Food and Agriculture in Papua New Guinea

edited by R. Michael Bourke and Tracy Harwood

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Cover: Yasisime from Asirangka village in the Aiyura basin, Eastern Highlands Province, weeds a peanut plot. Peanut is grown for both home consumption and for sale locally. It is grown in rotation with sweet potato to maintain soil fertility. The plot on the left contains sweet potato, the staple food in the highlands, and other food crops. Casuarina trees in the background shade Arabica coffee, the most important cash crop in the highlands. Photo by Mike Bourke.

Contents

Foreword

It gives me great pleasure to contribute the Foreword to this impressive book.

I have long held the view that subsistence agriculture underwrites the PNG cash economy. The cash sector should supplement and complement but not replace the subsistence sector. Agriculture in PNG provides direct benefits to over 80% of our population. A strong subsistence sector and the *wantok* system provide surrogate social welfare support for many people. The resilience of the rural majority was seen recently when steep increases in food prices caused considerable distress in many parts of the world. However, most rural people in PNG were spared the worst impact of these rises because of their strong subsistence base and cash income from agricultural export crops.

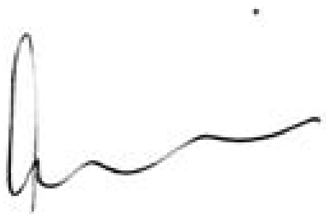
Agriculture is also important because it is a central part of our traditional cultures and maintains our lifestyles. It also reduces poverty among rural people and lessens migration to towns. While the mining and petroleum sectors are presently important to the economy, agriculture uses renewable resources that will continue to be critical to the PNG economy long into the future.

I am attracted to many aspects of this important book. It contains information about the significance of subsistence food production, the role of export cash crops, and details on forestry and fisheries. I was particularly pleased to see the wide variety of subjects covered including, for example, population, land use, global climate change, animal husbandry, gender issues and access to services. I was also pleased to note that the authors have included information on addressing current constraints to the expansion of agriculture.

The book is written in language that is readily accessible to non-specialists. It will be a valuable teaching resource for senior high school and university students. I commonly hear advisers new to PNG saying that there is no information available on a particular topic, or that something that has been tried before should be tried again. This book makes that 'missing' information available in one place and describes the history of previous attempts to, for example, introduce new crops or bring about rural development.

As a former director of the PNG National Planning Office, it is clear to me that much of the information in this book will and should form the basis for planning further agricultural development and indeed form the basis for defining development policies for PNG. The authors have not been afraid to put forward their expert opinions on possible future trends. They have also constructively addressed some contentious issues in the interests of agricultural development in PNG.

I congratulate the authors, editors and The Australian National University for producing this book and warmly commend it.



Charles W. Lepani
Papua New Guinea High Commissioner
to Australia, Canberra
October 2008

Contributors

Most of this book was written by R. Michael Bourke and Bryant Allen. Some sections were contracted to specialists. Matthew Allen wrote 11 sections of Part 5.

Bryant Allen

Bryant Allen is a Senior Fellow with the Land Management Group, Research School of Pacific and Asian Studies (RSPAS), The Australian National University. He has carried out research in the Cook Islands in the 1960s and in rural Papua New Guinea (PNG) from the early 1970s to the present. He has worked at the University of PNG, the PNG Department of Environment and Conservation and the PNG National Research Institute. He has researched in many parts of rural PNG, in particular in the Dreikikir area of East Sepik and the Tari area of Southern Highlands. His main interests are in the sustainability of agricultural systems, in particular shifting cultivation systems; rural development; rural poverty; and food security. **Authored:** 1.1–1.7, 1.9–1.12, 1.14–1.15, 2.5, 3.6–3.12, 6.1–6.10.

Matthew Allen

Matthew Allen is a Postdoctoral Fellow with the Resource Management in Asia-Pacific Program, RSPAS, The Australian National University. Matthew has conducted research on various aspects of the societies and environments of Melanesia since 1997. His PhD research examined the relationships between the state, identity, resources and conflict in Solomon Islands. His research interests are resource conflict and identity politics in Melanesia in general and Solomon Islands in particular, with further interests in smallholder agriculture, food security and rural development. **Authored:** 5.2, 5.4–5.13.

Kate Barclay

Kate Barclay is a Senior Lecturer with the International Studies program at the University of Technology, Sydney. Kate researches the social and political aspects of fisheries in the Asia–Pacific region. She is particularly interested in the connections between economic development and national identity, and globalisation, using fisheries enterprises as case studies. **Authored:** 2.10.

R. Michael Bourke

Mike Bourke is an independent consultant and an Adjunct Senior Fellow with the Land Management Group, RSPAS, The Australian National University. He has formal training as an agricultural scientist and human geographer and has been continuously involved in research and development work in village agriculture in PNG since 1970. He has worked in most parts of rural PNG. His research interests include relationships between people, crops and the environment; intensification of land use; climate change; sustainability of agriculture; food security; rural poverty; rural development; and root crop agronomy. **Authored:** History of agriculture, 1.8, 1.13, 2.1, 2.2, 2.4, 3.1–3.5, 4.2–4.4, 5.1, 5.3, 5.15–5.20; and significant contribution to all sections in Part 5.

John Gibson

John Gibson is a Professor of Economics at the Waikato Management School, University of Waikato, Hamilton, New Zealand, and a Visiting Fellow at the Center for Global Development, Washington, DC. He has previously worked as an adviser with the PNG Department of Agriculture and Livestock and as a researcher with the PNG Institute of National Affairs. His research interests include poverty measurement; the design and analysis of household survey data; and economic development, especially in China and other Asian and Pacific economies. **Authored:** 2.7–2.9.

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Tracy Harwood is an editor with the Land Management Group, RSPAS, The Australian National University. She has a Bachelor of Applied Science in Ecology and Natural Resources from the University of Canberra and is interested in environmental sciences. She has been editing since 2002 and is a member of the Canberra Society of Editors and the Australian and New Zealand Society of Indexers.

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Andrew McGregor

Andrew McGregor is an agricultural economist specialising in the Pacific islands. He currently manages the Trade and Development Office, Fiji. Over the past 30 years Andrew has worked in most Pacific island countries, and also in the eastern Caribbean and Hawaii. **Authored:** 4.1, 5.14, 5.21; contributed to future prospects for export crops in Part 5.

Alan Quartermain

Alan Quartermain is Dean of the School of Natural Resources, University of Vudal, Rabaul, PNG. He trained as an agricultural scientist and animal geneticist. He has taught at the University of PNG and University of Vudal, was Chief Scientist at the PNG National Agricultural Research Institute, and works as a consultant for the Food and Agriculture Organization of the United Nations. His research interests include livestock production, and agricultural research and development issues in developing countries. **Authored:** 2.6.

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Many people from the commercial sector, industry bodies and government departments in PNG provided data, as did some based in Australia and elsewhere. They include: Ganei Agodop, Joseph Aka, Will Akus, Stephen Althaus, Moses Alu, Ram Anatharaman, Theresa Arek, David Armour, David Bain, Felix Bakani, Valonna Baker, Sergei Bang, Paul Barker, Chew Kui Boo, Greg Bosa, Maurice Brownjohn, Guy Cameron, Paul Chatterton, John Cook, George Curry, Charles Dambui, Edwin Dawana, Robert DeBrouwere, Bob Densley, Frederic Dumortier, Warren Dutton, Geoff Fahey, Mathias Faure, Philip Franklin, Brad Furness, Chris Gard, Botu Gaupu, Anton Goonetilleke, John Goumei, Jim Greg, Marianne Grosclaude, Brian Gunn, Martin Gunther, Gaona Gwaibo, Peter Heywood, Neville Howcroft, Ross Humphries, Kasis Inape, Sharryl Ivahupa, Mike Jackson, Ron Jenkins, Mark Johnston, Vele Kagena, Patricia Kaiola, John Kaius, Aquina Kango, Pauka Karafa, Ram Karan, Henao Kari, Prescilla Kauni, John Kendiga, Jeff Kinch, Michael Knight, Gina Koczberski, Marcel Kuiper, Tom Kukhang, Lastus Kuniata, Hugh Laird, Leanne Lawrance, Phil Leahy, Malcolm Levett, Frank Lewis, Ishmel Libitino, David Loh, Tella Loie, Mark Lowe, Michael Lowe, Sue Lowe, Victor Maggio, John Mandich, Mike Manning, Anna Martin, David Mather, Leigh Matters, Wakasa Mecksaene, Rahman Mizanur, Jane Mogina, John Moxon, Jennifer Moyes, Kulala Mulung, John Nightingale, Norah Omot, Theresa Orim, Diane Ormsby, Ian Orrell, Dale Palmer, Nigel Parker, Sudari Pawiro, Andrew Pawley, John Petersen, Philip Pondikou, Kanawi Pouru, Gary Preston, Alan Quartermain, Sisiwaka Roah, Graeme Ross, Alan Rumsey, David Sali, Joselito Santiago, Wila Saweri, Brett Schofield, Reuben Sengere, Ian Sexton, Tim Sharp, Robert Shelton, Rob Small, John Sowei, Graeme Stowell, Willie Susuke, Ben Tara, Lauatu Tautea, Bruce Telfer, Stephen Tovita, Katie Tripp, Jack Tulvue, Ruth Turia, Roger Vallance, Michael Varapik, Phillip Vovola, Michael Waisime, Peter Walton, Tamzin Wardley, Nathan Wartovo, Jimmy Weiner, David Wilkin, Steve Woodhouse, Charles Yala, Andrew Yamanea and Sylvanius Yavisa.

Some sections were sent to specialists for comments. Those provided by Jack Golson on the history of agriculture were particularly comprehensive. Other reviewers were Chris Ballard, Kate Barclay, Paul Barker, Chew Kui Boo, John Burton, Brian Chung, George Curry, Peter Cusack, Warren Dutton, Colin Filer, Jim Fingleton, Phil Franklin, John Gibson, Anton Goonetilleke, Brian Gunn, Simon Haberle, Alfred Hartemink, Robin Hide, Braden Jenkin, Margaret Jolly, Gael Keig, Jeff Kinch, Lastus Kuniata, Hugh Laird, Joseph Lelang, Anthony Lewis, John McAlpine, Andrew McGregor, Mark Mosko, Ian Orrell, Alan Quartermain, Ian Sexton, Tim Sharp, Rob Small, John Spriggs, Bill Standish and Phillip Vovola.

Most of the information on village-sector agriculture was collected from hundreds of people from every district in PNG who willingly gave their time and immense knowledge about their food production and cash crop systems. One of the aims of this book is to explain the critical importance to PNG's national economy of village agriculture through the production of food, shelter and cash crops.

The book was produced by members of the Land Management Group, Research School of Pacific and Asian Studies, The Australian National University. As well as the editors, Laura Vallee (data organisation) and Bryant Allen (editing) made a significant input. Others who contributed included Matthew Allen, Karen Fisher, Quintin Gravatt, Amber Pares, Natalie Stuckings and Veerle Vlassak. Graphs and pie charts were generated in house. Maps were drawn by Kay Dancey, Cartography Unit, ANU. Additional figures were provided by Catherine Eadie, Philippe Rekacewicz and Robert Rohde. Design was by Sam Highley. Several members of the Canberra Society of Editors advised informally on some editing conventions. Funding was provided by the Research School of Pacific and Asian Studies at ANU, the Australian Government through AusAID, and by members of the Land Management Group from consulting income.

The assistance of all those named above is acknowledged with thanks. Responsibility for any errors or omissions rests with the authors of individual sections.

Acronyms and initialisms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AGSYS	agricultural system
ANU	The Australian National University
AusAID	Australian Agency for International Development
AVHRR	Advanced Very High Resolution Radiometer
CBO	community-based organisation
CCI	Cocoa Coconut Institute of PNG
CIC	Coffee Industry Corporation Ltd
CIMC	Consultative Implementation and Monitoring Council
CLTC	Christian Leaders Training College
CMB	Copra Marketing Board
COPD	Community Oil Palm Development
CPI	consumer price index
CRES	Centre for Resource and Environmental Science (ANU)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CU	census unit
DAL	Department of Agriculture and Livestock
DASF	Department of Agriculture, Stock and Fisheries
DEC	Department of Environment and Conservation
DHS	Demographic and Health Survey
DIS	delivered-in-store
DNPM	Department of National Planning and Monitoring
DPI	Department of Primary Industry
DSG	District Support Grant
DSIP	District Services Improvement Program
EBC	Evangelical Brotherhood Church Inc.
ENSO	El Niño Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FFB	fresh fruit bunch (oil palm)
FIMS	Forest Resource Information System
FPDA	Fresh Produce Development Agency Ltd
GIS	geographical information system
HIV/AIDS	human immunodeficiency virus/ acquired immune deficiency syndrome
IASER	Institute of Applied Social and Economic Research
IFTA	Insect Farming and Trading Agency
INA	Institute of National Affairs
IPCC	Intergovernmental Panel on Climate Change

ITTO	International Tropical Timber Organization
KIK	Kokonas Indastri Koporesen
LAES	Lowlands Agricultural Experiment Station, Keravat
LDC	Livestock Development Corporation Ltd
LMS	London Missionary Society
LSS	land settlement scheme
MASP	Mapping Agricultural Systems of Papua New Guinea Project
MP	member of parliament
MTDS	Medium Term Development Strategy
NAC	National Agricultural Council
NACS	National AIDS Council Secretariat
NADP	National Agriculture Development Plan
NAIS	National Agricultural Information System
NAQIA	National Agriculture Quarantine and Inspection Authority
NARI	National Agricultural Research Institute
NBPOL	New Britain Palm Oil Limited
NES	nucleus estate and smallholder (model)
NFA	National Fisheries Authority
NFB	National Forestry Board
NFS	National Forestry Service
NGO	non-government organisation
NIS	nut-in-shell
NNS	National Nutrition Survey
NPK	nitrogen–phosphorus–potassium fertiliser
NPO	National Planning Office
NSO	National Statistical Office of PNG
OPGA	Oil Palm Growers' Association
OPIC	Oil Palm Industry Corporation
OPRA	Oil Palm Research Association
ORD	Office of Rural Development
PDS	Provincial Data System
PNG	Papua New Guinea
PNGCC	Papua New Guinea Coconut Commodities
PNGFA	Papua New Guinea Forest Authority
PNGRIS	Papua New Guinea Resource Information System
POPA	Palm Oil Producers' Association
PRA	participatory rural appraisal
RAMS	Road Asset Management System
RHS	rural household survey
RIC	Rural Industries Council
RMU	resource mapping unit
RRA	rapid rural appraisal
SGS	Société Générale de Surveillance
SIB	Spice Industry Board
SOI	Southern Oscillation Index
SSTC	South Seas Tuna Corporation
TPC	Tactical Pilotage Chart
UN	United Nations
UNICEF	United Nations Children's Fund
US	United States of America
USDA	United States Department of Agriculture
VOP	village oil palm
WWF	(formerly) World Wide Fund for Nature

Botanical names

Staple foods

Common name	Scientific name
Banana	*Musa* cvs
Cassava	*Manihot esculenta*
Coconut	*Cocos nucifera*
Cordyline	*Cordyline fruticosa*
Corn (maize)	*Zea mays*
Irish potato	*Solanum tuberosum*
Kudzu	*Pueraria lobata*
Polynesian arrowroot	*Tacca leontopetaloides*
Queensland arrowroot	*Canna edulis*
Rice	*Oryza sativa*
Sago	*Metroxylon sagu*
Sago	*Metroxylon salomonense*
Sorghum	*Sorghum bicolor*
Sugar cane	*Saccharum officinarum*
Sweet potato	*Ipomoea batatas*
Taro	*Amorphophallus paeoniifolius*
Taro (taro tru)	*Colocasia esculenta*
Taro, Chinese	*Xanthosoma sagittifolium*
Taro, giant	*Alocasia macrorrhizos*
Taro, swamp	*Cyrtosperma chamissonis*
Wheat	*Triticum aestivum*
Yam	*Dioscorea nummularia*
Yam	*Dioscorea pentaphylla*
Yam, aerial	*Dioscorea bulbifera*
Yam, greater	*Dioscorea alata*
Yam, lesser	*Dioscorea esculenta*
Yam, white	*Dioscorea rotundata*

Vegetables

Common name	Scientific name
Aibika	*Abelmoschus manihot*
Amaranthus	*Amaranthus blitum*
Amaranthus	*Amaranthus caudatus*
Amaranthus	*Amaranthus cruentus*
Amaranthus	*Amaranthus dubius*
Amaranthus	*Amaranthus tricolor*
Bean, adzuki	*Vigna angularis*
Bean, broad	*Vicia faba*
Bean, climbing	*Phaseolus vulgaris*
Bean, common	*Phaseolus vulgaris*
Bean, dwarf	*Phaseolus vulgaris*
Bean, jack	*Canavalia ensiformis*
Bean, lablab	*Lablab purpureus*
Bean, lima	*Phaseolus lunatus*
Bean, mung (bean sprouts)	*Vigna radiata*
Bean, rice	*Vigna umbellata*
Bean, snake	*Vigna unguiculata* cv. group Sesquipedalis

Vegetables (continued)

Bean, winged	*Psophocarpus tetragonolobus*
Beetroot	*Beta vulgaris* cv. group Garden Beet
Broccoli	*Brassica oleracea* cv. group Broccoli
Brussels sprout	*Brassica oleracea* cv. group Brussels Sprouts
Cabbage, Chinese	*Brassica rapa* cv. group Chinese cabbage
Cabbage, head	*Brassica oleracea* cv. group White Headed Cabbage
Capsicum	*Capsicum annuum*
Carrot	*Daucus carota*
Castor	*Ricinus communis*
Cauliflower	*Brassica oleracea* cv. group Cauliflower
Celery	*Apium graveolens* var. *dulce*
Ceylon spinach	*Basella alba*
Chilli	*Capsicum frutescens*
Choko (chayote)	*Sechium edule*
Coral tree	*Erythrina variegata*
Cowpea	*Vigna unguiculata* cv. group Unguiculata
Cucumber	*Cucumis sativus* cv. group Slicing Cucumber
Cyanotis	*Cyanotis moluccana*
Dicliptera	*Dicliptera papuana*
Eggplant	*Solanum melongena* cv. group Common Eggplant
Ficus wassa	*Ficus wassa*
Garlic	*Allium sativum* cv. group Common Garlic
Ginger	*Zingiber officinale*
Gourd, bottle	*Lagenaria siceraria*
Gourd, wax	*Benincasa hispida* cv. group Wax Gourd
Highland *kapiak*	*Ficus dammaropsis*
Job's tears	*Coix lacryma-jobi*
Kalava	*Ormocarpum orientale*
Kangkong	*Ipomoea aquatica*
Karakap	*Solanum americanum*
Kohlrabi	*Brassica oleracea* cv. group Kohlrabi
Kumu musong	*Ficus copiosa*
Leek	*Allium ampeloprasum* cv. group Leek
Lemon grass	*Cymbopogon citratus*
Lettuce	*Lactuca sativa*
Marrow	*Cucurbita pepo*
Oenanthe (water dropwort)	*Oenanthe javanica*
Onion	*Allium cepa* cv. group Common Onion
Pak choi	*Brassica rapa* cv. group Pak Choi
Parsley	*Petroselinum crispum*
Pea	*Pisum sativum*
Peanut	*Arachis hypogaea*
Pigeon pea	*Cajanus cajan*
***Pitpit*, highland**	*Setaria palmifolia*
***Pitpit*, lowland**	*Saccharum edule*
Pumpkin	*Cucurbita moschata*
Radish, red	*Raphanus sativus* cv. group Small Radish
Rhubarb	*Rheum ×cultorum*
Rorippa	*Rorippa schlechteri*
Rungia	*Rungia klossii*
Russian comfrey	*Symphytum asperrimum*
Shallot	*Allium cepa* cv. group Aggregatum
Silverbeet	*Beta vulgaris* cv. group Spinach Beet
Soya bean	*Glycine max*
Spinach	*Spinacia oleracea*
Spring onion	*Allium cepa* cv. group Aggregatum
Tomato	*Lycopersicon esculentum*

Vegetables (continued)

Trichosanthes pulleana	*Trichosanthes pulleana*
Tulip	*Gnetum gnemon*
Turnip	*Brassica rapa* cv. group Vegetable Turnip
Valangur	*Polyscias verticillata*
Wandering Jew	*Commelina diffusa*
Watercress	*Rorippa nasturtium-aquaticum*
Yam bean	*Pachyrhizus erosus*
Zucchini	*Cucurbita pepo*

Fruit

Common name	Scientific name
Apple	*Malus* spp.
Avocado	*Persea americana*
Brazil cherry	*Eugenia uniflora*
Bukabuk	*Burckella obovata*
Bullock's heart	*Annona reticulata*
Cape gooseberry	*Physalis peruviana*
Carambola (five corner)	*Averrhoa carambola*
Cherimoya	*Annona cherimolia*
Cumquat	*Fortunella japonica*
Custard apple (sweetsop)	*Annona squamosa*
Durian	*Durio zibethinus*
Egg tree	*Garcinia xanthochymus*
Elder	*Sambucus nigra*
Golden apple	*Spondias cytherea*
Governor's plum	*Flacourtia indica*
Granadilla	*Passiflora quadrangularis*
Grapefruit	*Citrus paradisi*
Guava	*Psidium guajava*
Guava, cherry	*Psidium cattleianum*
Jackfruit	*Artocarpus heterophyllus*
Langsat	*Lansium domesticum*
Lemon	*Citrus limon*
Lime	*Citrus aurantifolia*
Longan	*Euphoria longan*
Loquat	*Eriobotrya japonica*
Malay apple	*Syzygium malaccense*
Malay apple, giant	*Syzygium megacarpa*
Mandarin	*Citrus reticulata*
Mango	*Mangifera indica*
Mango, traditional	*Mangifera minor*
Mangosteen	*Garcinia mangostana*
***Marita* pandanus**	*Pandanus conoideus*
Mon	*Dracontomelon dao*
Mulberry	*Morus nigra*
Naranjilla	*Solanum quitoense*
Nectarine	*Prunus persica* var. *nectarina*
Orange	*Citrus sinensis*
Pandanus, coastal	*Pandanus tectorius*
Parartocarpus	*Parartocarpus venenosa*
Passionfruit, banana	*Passiflora mollissima*
Passionfruit, lowland yellow	*Passiflora edulis* f. *flavicarpa*
Passionfruit, purple	*Passiflora edulis* f. *edulis*
Pawpaw (papaya)	*Carica papaya*
Peach	*Prunus persica*
Persimmon	*Diospyros kaki*
Pineapple	*Ananas comosus*
Plum, Japanese	*Prunus* spp.
Pomegranate	*Punica granatum*
Pomelo	*Citrus maxima*
Pouteria	*Pouteria maclayana*
Pulasan	*Nephelium mutabile*
Rambutan	*Nephelium lappaceum*
Raspberry, black	*Rubus lasiocarpus*
Raspberry, red	*Rubus moluccanus*
Raspberry, red	*Rubus rosifolius*

Fruit (continued)

Rockmelon (cantaloupe)	*Cucumis melo*
Rukam	*Flacourtia rukam*
Santol	*Sandoricum koetjape*
Soursop	*Annona muricata*
Star apple	*Chrysophyllum cainito*
Strawberry	*Fragaria spp.*
***Suga prut* (highland yellow passionfruit)**	*Passiflora ligularis*
Tamarillo (tree tomato)	*Cyphomandra betacea*
Tamarind	*Tamarindus indica*
***Ton* (*taun*)**	*Pometia pinnata*
Watermelon	*Citrullus lanatus*
Watery rose apple	*Syzygium aqueum*

Nuts

Common name	Scientific name
Breadfruit	*Artocarpus altilis*
Candle nut	*Aleurites moluccana*
Cashew	*Anacardium occidentale*
Castanopsis	*Castanopsis acuminatissima*
Dausia	*Terminalia megalocarpa*
Elaeocarpus womersleyi	*Elaeocarpus womersleyi*
Finschia	*Finschia chloroxantha*
Galip	*Canarium decumanum*
Galip	*Canarium harveyi*
Galip	*Canarium indicum*
Galip	*Canarium lamii*
Galip	*Canarium salomonense*
***Karuka*, planted**	*Pandanus julianettii*
***Karuka*, wild**	*Pandanus antaresensis*
***Karuka*, wild**	*Pandanus brosimos*
Macadamia	*Macadamia integrifolia*
Macadamia	*Macadamia tetraphylla*
Okari	*Terminalia impediens*
Okari	*Terminalia kaernbachii*
Omphalea gageana	*Omphalea gageana*
Pao	*Barringtonia edulis*
Pao	*Barringtonia novae-hiberniae*
Pao	*Barringtonia procera*
Pecan	*Carya illinoensis*
Polynesian chestnut (*aila*)	*Inocarpus fagifer*
Sea almond (*talis*)	*Terminalia catappa*
***Sis* (*solomon*)**	*Pangium edule*
Tulip	*Gnetum gnemon*

Stimulants

Common name	Scientific name
Betel nut (*buai*)	*Areca catechu*
Betel nut, highland	*Areca macrocalyx*
Betel pepper, highland	*Piper gibbilimbum*
Betel pepper, lowland	*Piper betle*
Kava	*Piper methysticum*
Marijuana	*Cannabis sativa*
Tobacco	*Nicotiana tabacum*

Cash crops

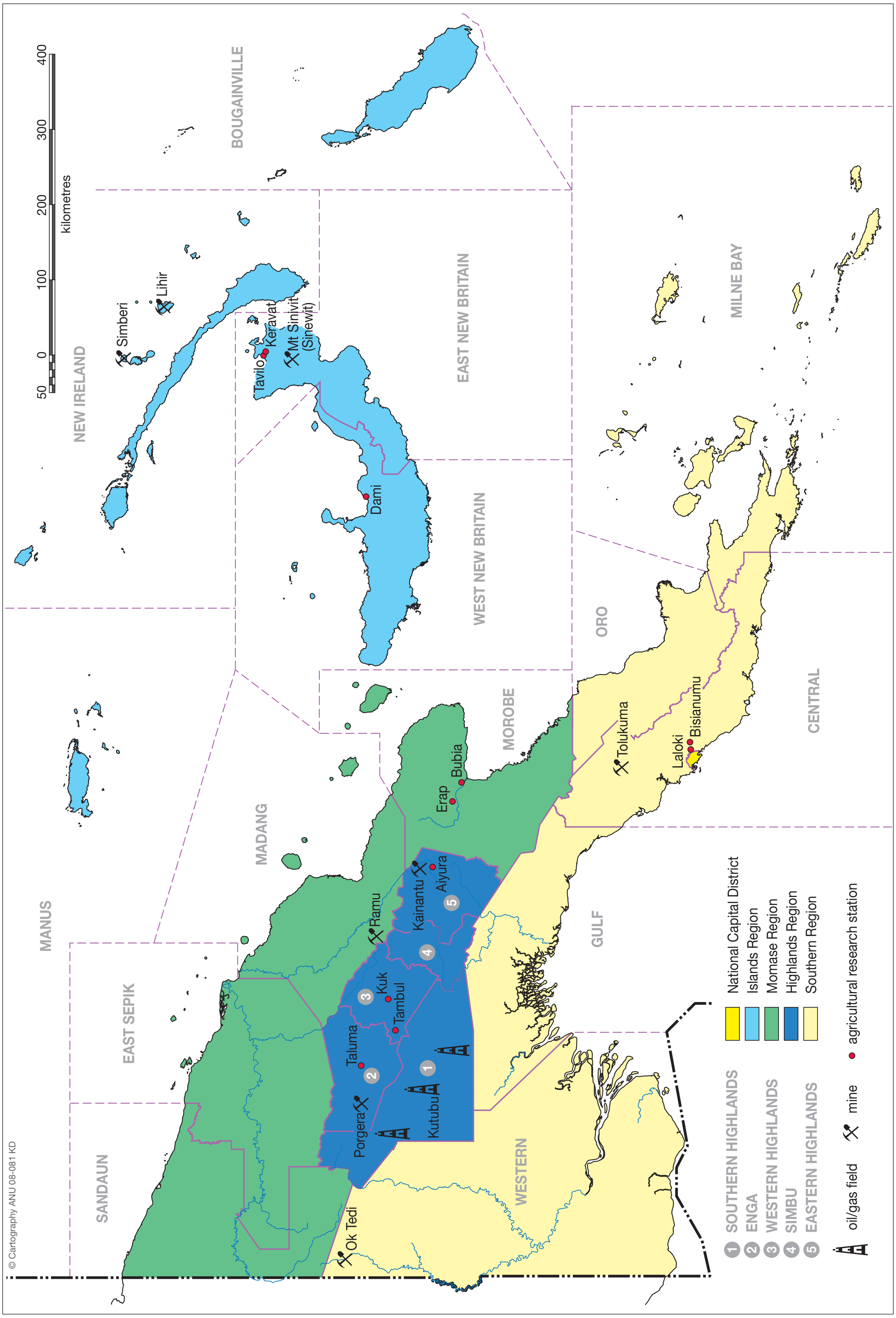
Common name	Scientific name
Annatto (bixa)	*Bixa orellana*
Balsa	*Ochroma lagopus*
Black pepper	*Piper nigrum*
Cardamom	*Elettaria cardamomum*
Chilli	*Capsicum frutescens*

Cash crops (continued)

Cinnamon	*Cinnamomum verum*
Citronella grass	*Cymbopogon nardus*
Cocoa	*Theobroma cacao*
Coffee, Arabica	*Coffea arabica*
Coffee, Robusta	*Coffea canephora* var. *robusta*
Coconut	*Cocos nucifera*
Ginger	*Zingiber officinale*
Japanese mint	*Mentha arvensis*
Jatropha	*Jatropha curcas*
Kapok	*Ceiba pentandra*
Lemon grass	*Cymbopogon citratus*
Nutmeg	*Myristica argentea*
Nutmeg	*Myristica fragrans*
Oil palm	*Elaeis guineensis*
Patchouli	*Pogostemon cablin*
Pyrethrum	*Chrysanthemum cinerariaefolium*
Rubber, assam	*Ficus elastica*
Rubber, para	*Hevea brasiliensis*
Tea	*Camellia sinensis*
Turmeric	*Curcuma domestica*
Vanilla	*Vanilla planifolia*
Vanilla	*Vanilla tahitensis*

Forest products

Common name	Scientific name
Acacia	*Acacia crassicarpa*
Acacia	*Acacia mangium*
Burckella	*Burckella* spp.
Cajuput oil	*Asteromyrtus symphyocarpa*
Calophyllum	*Calophyllum* spp.
Casuarina (*yar*)	*Casuarina oligodon*
Chinese water chestnut	*Eleocharis dulcis*
Copal gum	*Agathis* spp.
Cordyline	*Cordyline fruticosa*
Dammar	*Vatica papuana*
Dillenia	*Dillenia* spp.
Eaglewood	*Gyrinops ledermannii*
Eucalyptus (*kamarere*)	*Eucalyptus deglupta*
Eucalyptus	*Eucalyptus pellita*
Hibiscus	*Hibiscus tiliaceus*
Hoop pine	*Araucaria cunninghamii*
Ivory nut	*Metroxylon amicarum*
Kamarere	*Eucalyptus deglupta*
Klinki pine	*Araucaria hunsteinii*
Kwila	*Intsia bijuga*
Malas	*Homalium* spp.
Massoi	*Cryptocarya massoy*
Mersawa	*Anisoptera* spp.
New Guinea walnut (*mon*)	*Dracontomelon dao*
Noni	*Morinda citrifolia*
Perennial cane grass	*Coix gigantea*
Pinus	*Pinus* spp.
Planchonella	*Pouteria* spp.
Red canarium (*galip*)	*Canarium indicum*
Red cedar	*Toona ciliata*
Rosewood	*Pterocarpus indicus*
Rubber	*Hevea brasiliensis*
Sandalwood	*Santalum macgregorii*
Sisal	*Agave sisalana*
Teak	*Tectona grandis*
Terminalia	*Terminalia* spp.
Tigaso oil	*Buchanania* spp.
Tigaso oil	*Campnosperma brevipetiolata*
Ton (*taun*)	*Pometia pinnata*



The five regions of Papua New Guinea, mine sites mentioned in the text, and agricultural research stations


MANUS
ADMIRALTY ISLANDS
Bismarck Bay
LORENGAU
Manus Is
Fedarb Is
Rambutyo Is
Mbuke Is
Lou Is
Pam Is
Baluan Is
BISMAR
SANDAUN
EAST SEPIK
VANIMO
Sissano Lagoon
Bewani
Aitape
Vokeo Is
Dagua
WEWAK
Amanab
Dreikikir
Nuku
Maprik
Bainyik
Wosera
Murik Lakes
Gavien
Sepik
Angoram
Ama
Ambunti
Manam Is
Bogia
MADANG
Keram
Ramu
Yapsiei
May
Karkar Is
Bagabag Is
ADELBERT RA.
Yuat
Gogol
Telefomin
Tabubil
Oksapmin
Lagaip
SCHRADER RA.
Kaironk
Simbai
MADANG
Long Is
Siassi Islands
Kopiago
Kompiam
Lai
Jimi
Rai Coast
Porgera
Sirunki
WABAG
3
Laiagam
2
Wapenamanda
Ningerum
Koroba
Kandep
Tari
Tambul
Kuk
Wahgi
Mt Wilhelm
Bundi
Saidor
FINISTERRE RA.
Umboi Is
Dumpu
Gembogl
Teptep
Wasu
Margarima
MOUNT HAGEN
Kudjip
Kerowagi
Gusap
Ok Tedi
Nebilyer
KUNDIAWA
GOROKA
Wantoat
Sialum
Nipa
MENDI
Gumine
Mt Elimbari
Asaro
SARAWAGET RA.
Kabwum
Kiunga
Strickland
Nomad
Nembi
1
Ialibu
4
Kainantu
Henganofi
Arona
Kaiapit
Huon Peninsula
Pindiu
Fly
Great Papuan Plateau
Lake Kutubu
Karimui
Lufa
Ukarumpa
Nadzab
Ogeranang
Finschhafen
Pimaga
Erave
5
Okapa
Markham
Gobari
Situm
Mt Bosavi
Erave
Wopasali
Lamari
Imani
Patep No.2
LAE
Lake Murray
Watut
Wampit
Wagau
Wonenara
Kikori
Purari
Snake
Marawaka
Mumeng
Busama
Bosset
Menyamya
Bulolo
MOROBE
WESTERN
Aird Hills
Aseki
Wau
Kikori
Koravaki
Kanabea
Tauri
Murua
Epo
KEREMA
Lakekamu
Garaina
Suki
Fly
Balimo
GULF
Waria
GULF OF PAPUA
Bereina
Oriomo
Yule Is
Kokoda
POPON
Managalas Plateau
DARU
Afore
Galley Reach
Saibai Is
Sogeri
PORT MORESBY
Kemp Welch
Kupiano
1 SOUTHERN HIGHLANDS
2 ENGA
3 WESTERN HIGHLANDS
4 SIMBU
5 EASTERN HIGHLANDS
CENTRAL
Cape Rodney
© Cartography ANU 08-081 KD

Locations mentioned in the text

Conventions, data sources and limitations

Conventions

Currency

The value of production and exports is usually expressed in PNG kina, with values in US dollars also used in some appendix tables. Australian pounds was the currency used in PNG until early 1966 and pounds have been converted to Australian dollars by multiplying by two. Australian dollars were then used until April 1975, when the kina was introduced. Values in Australian dollars prior to 1975 are expressed as kina throughout the book. Figure 4.1.1 and Table A4.1.1 display the exchange rates used in the conversions between the kina and Australian dollar and US dollar.

The symbols used for the main currencies are:

K	PNG kina
A$	Australian dollar
US$	United States dollar

The kina lost value relative to the US dollar after 1994, and particularly after 1998. Hence the value of exports from PNG in kina terms generally increased after the late 1990s (Figure 5.2.4). However, the buying power of the kina decreased at the same time, so real returns to growers are generally less than they appear in figures showing the export value for each cash crop (Part 5).

Food crop categories

A number of terms could be used to describe the most important carbohydrate foods grown in PNG. We have used the term 'staple food crop' as a category for these crops, the most important being sweet potato, sago, banana and various types of taro and yam. Strictly speaking, the term 'staple food' refers to a food that provides the most food energy in a population's diet. So a crop might be the staple food for some people, but not for others. Alternative terms we could have used and which would have been more precise in some contexts include 'starchy food', 'carbohydrate food', 'energy food', 'main food crop' or 'most important food crop.' A number of food crops grown in PNG are difficult to classify in crop categories. We have included banana, coconut, corn, Irish potato and sugar cane with staple foods. Peanut is included in the vegetable class, while breadfruit is included with edible nuts.

We use the term 'stimulant' for a group of substances that people use to alter their mood, emotion or perception. The substances covered here (tobacco, betel nut, marijuana, caffeine, alcohol and kava) are not all stimulants in a medical sense, but the term is less emotive than alternative names such as 'narcotic' or 'drug' and less technical than the more precise term 'psychoactive drug'.

The common names of food crops and plants are used as much as possible in this book. Scientific names are used where common names are not known or used, or to distinguish between similar species. For example, *galip* is the common name for a nut belonging to the genus *Canarium*, of which there are many species. In the text, the nut may be referred to by its full scientific name to make it clear which *galip* species is being discussed. A table of all plant common and scientific names is on page xiv.

Imperial measurements

Some historical data is available only in imperial measurements, such as tons or acres. We have converted all data to metric units, which have been used in PNG since 1972.

Population

Official population data from the 2000 National Census has been used throughout this book. The total population in mid 2000 was 5.2 million people. Census units, the lowest unit of the PNG census, were used to group the population into urban, rural and rural non-village classes. ('Rural non-village' locations include mining settlements, logging camps, mission stations, schools and research stations.) Of the total, 81% (4.2 million) were rural villagers; 13% (0.7 million) lived in urban areas; and 6% (0.3 million) lived in rural non-village locations (Table 1.1.1). The average number of people per household in PNG is 5.1, so to convert population figures to number of households, divide by 5.1. The mid 2008 PNG population was estimated by the Secretariat of the Pacific Community to be 6.5 million people.

Most population data used in tables and figures are for rural villagers, where we use the term 'rural population'. These figures do not include the rural non-village population. However, some analyses present data for the entire provincial or national population. Readers should note the distinction between 'rural population' and 'total population' in column headings and graph axes. In the x-axis of graphs, the term 'Central' refers to the rural village population only in Central Province, whereas the term 'Central + NCD' includes the total population of Central Province and the National Capital District (Port Moresby).

Provincial names

The names commonly used for some provinces differ from the official (and older) names. We have used the more commonly used names, that is, Oro, Sandaun and Simbu rather than Northern, West Sepik and Chimbu. We use the current province name rather than earlier province names, even when referring to historical data. Some provinces have been split over the past 60 years: they are Sepik into East Sepik and Sandaun; New Britain into East New Britain and West New Britain; Central Highlands into Southern Highlands, Western Highlands and Eastern Highlands; Eastern Highlands into Eastern Highlands and Simbu; and Western Highlands into Western Highlands and Enga.

When we commenced this book, Bougainville was one of 19 provinces. On 15 June 2005, its status changed to the Autonomous Region of Bougainville. We have used the term 'Bougainville' throughout rather than the post 2005 name.

Data sources

Data in this book come from many places and are noted under 'Sources' at the end of each section. Statements are not attributed to an author in the text, although they are sometimes attributed in footnotes.

Some data sources for tables and figures are given as organisations with or without dates. If data were obtained directly from an organisation or government department (for example, from the Department of Agriculture and Livestock, DAL), then no date is supplied. When data are from a published source, a date is given and the bibliographic details are listed at the end of the relevant section, for example, DAL (1992).

The Papua New Guinea Resource Information System (PNGRIS), developed by CSIRO in Australia and PNG Department of Primary Industry (now DAL) in the 1980s and 1990s, was widely used in Part 1. It contains information on natural resources, land use and population distribution in PNG, with data in a mappable form (or geographical information system). The database is described in a number of publications (see Section 1.15 for the references).

Another significant data source was the Mapping Agricultural Systems of Papua New Guinea Project (MASP) database, particularly for Part 3. This was developed by members of the Land Management Group at The Australian National University and is based on extensive fieldwork in the 1990s (see Section 1.15).

Much of the data are presented in about 380 tables, figures and maps. Smaller tables are contained in the body of the book. Larger and more complicated tables have been placed in an appendix. These are identified by the letter 'A' in front of the table number. For example, Table A6.7.1 is the first appendix table for Section 6.7. The appendix tables are not published in the paper version of this book, but are contained in the accompanying compact disk. Data for most figures are given in appendix tables, so that they can be re-analysed by users or extended in the future. Subject to funding availability, it is planned to make this book available on the web in a form where tables can be downloaded as Excel spreadsheets.

Data limitations

Most numerical data in this book has an error component. Where data are presented without the term 'estimated' the data are believed to be fairly accurate, that is, to be within +/– 15% of the real value. This is the case for the volume and value of most export crops and those statistics derived directly from the PNGRIS and MASP databases.

The term 'estimated' is used to indicate that the data are likely to be less accurate, often because an analysis is based on a number of assumptions. An example is estimates of production of staple food crops in 2000 (Tables 2.2.1, A2.2.1, A2.2.2).

Generally the size of the possible error is not given. Where we suspect that an estimate may have a particularly large error component, this is noted as a footnote, but we have usually chosen not to present data that seems to be particularly inaccurate.

There are two estimates of the source of foods consumed in PNG: one done as a *consumption survey* as part of the PNG Household Survey in 1996; and the second one as *production estimates* for 2006 done for this book. A comparison of the detailed results is useful as it indicates the order of errors in these two studies (see Table A2.1.1).

Data for the volume and value of export crops is likely to be fairly accurate, but errors are apparent, even with data for the same year from the same industry body. We have spent a lot of effort in attempting to resolve conflicting data, but have not always been successful. The reliability of some data appears to decrease in recent years, particularly since the late 1990s. We chose to present data on export crops from the industry bodies rather than the more commonly used data from the Bank of Papua New Guinea. Our reasoning is that data from the industry bodies is more likely to be accurate, but this appears to be not always so.

Export crops data from the Bank of PNG has the advantage of being consistent and readily available on the internet <http://www.bankpng.gov.pg/>. A disadvantage is that the categories used by the bank tend to reflect the PNG economy in past decades and have not been adjusted for changes in the economy, such as the relative decline in the importance of rubber and copra and the rise in production of other commodities. In the case of oil palm, data from the large processing companies is more accurate as the Bank of PNG data refers only to crude palm oil and does not include palm kernel oil, refined palm oil or palm kernel expellent.

Generally we have given the year when estimates were made, except for those derived mainly from PNGRIS and MASP. We have presented the most recent available data. We use older data where there is no more reliable recent data and the older data tells an important story. Data on the volume and value of export crops in Part 5 is presented up to 2006 or 2007, depending on data availability.

The estimates of cash income from the MASP database have changed since they were recorded in the early to mid 1990s and standardised in 1998 (Table 5.1.1). We have presented these estimates as there is no more recent detailed information on cash income for rural people, particularly for the informally marketed commodities such as fresh food, betel nut, firewood and fish. Despite changes in kina terms of income from agricultural sources over the past 15 years, the relative ranking of the sources of cash income has not changed greatly over this period.

Sources of information about Papua New Guinea agriculture

A large volume of information about agricultural surveys, research and many other aspects of rural development exists for PNG, and is contained in published and unpublished books, reports and papers. These documents can be identified through printed and electronic bibliographies.[1] Four major electronic bibliographies have been developed for agriculture, rural development and related topics in PNG. These databases do not give access to the papers themselves, but they indicate what literature is available and often where it can be located.

PNG National Agricultural Information System

The National Agricultural Information System (NAIS) is primarily a library catalogue of the holdings of 19 libraries of seven PNG agricultural institutions. Of the electronic systems described here, it is the only one based in PNG. The system comprises over 32 000 entries, and includes an early version of the PNG Agriculture Literature Database (see below) plus other materials found in partner libraries. Included in NAIS are over 600 agricultural titles published in PNG, from technical bulletins to extension leaflets. Many are in electronic format. The system uses Inmagic DB/TextWorks software, with all edited records conforming to international bibliographic and library standards. Subject descriptors follow the *CAB Thesaurus*. The system is coordinated from the NARI Library at Bubia.[2] The database is also accessible on the internet at <http://www.pngnais.org/>, although not all the functions of the desktop version have been implemented. The desktop version has been distributed to appropriate institutions throughout PNG.

1 For example, publications arising from conferences devoted to food production and human nutrition in PNG between 1970 and 1999 are listed by Bourke (2001).

2 In 2008 the administrator of the NAIS bibliography was Ms Irene Okpul (irene.okpul@nari.org.pg).

PNG Agriculture Literature Database

The PNG Agriculture Literature Database ('AgBib') was developed by the Land Management Group at The Australian National University. The focus of AgBib is agriculture in PNG, but it includes other topics relating to rural development. The database contains more than 16 000 entries. The original bibliography was developed by Robin Hide (see below), using EndNote software. A feature of the database is a comprehensive keyword list that is drawn from the *CAB Thesaurus*. Increasingly, where digital full text versions of papers exist, these are being linked to the related bibliographic record. Many of the references have been checked against originals and the database contains few errors. An early version of the database can be accessed on the internet at <http://database.anu.edu.au/rspas/hug/pngagbib/>. Up-to-date copies of the bibliography (about 7 MB in size) are available from the Land Management Group (lmg@anu.edu.au).

An important component of AgBib is references to unpublished reports and papers, known as 'grey literature', going back to the 1950s. Large numbers of unpublished reports produced on PNG agriculture have not been deposited in a central archive, such as the PNG National Library. The Land Management Group has copies of many of these reports, which will be archived in the Pacific Research Archive at the ANU Library. If funds become available this literature will be scanned and made available on the internet.

Hays's New Guinea bibliography

Terence Hays (thays@ric.edu) at Rhode Island College in the United States has developed and maintains an ethnographic bibliography for the island of New Guinea, that is, Indonesian Papua and mainland PNG (Momase, Highlands and Southern regions). Literature about ethnic groups is the main focus, with less information relating specifically to agriculture. About two-thirds of the entries refer to PNG and the rest to Papua. An internet version of the bibliography contains over 21 000 annotated entries and is located at <http://www.papuaweb.org/bib/hays/ng/intro.html>. A feature of this database is that all entries have been checked against originals and it is the most accurate of the electronic bibliographies reviewed here.

Hide's New Guinea bibliography

Robin Hide maintains a personal research database that has been built up over a 40-year period. It includes publications on agriculture, health, ecology and other topics focused on New Guinea (both Papua New Guinea and Papua, Indonesia). It contains some 43 000 entries, of which about 36 000 concern New Guinea (as at July 2008). The bibliography uses EndNote software. An earlier version of the bibliography formed the beginning of the PNG Agriculture Literature Database. As a personal, work-in-progress database, entries are not standardised, nor are all checked against originals. The database is not publicly available, but printed or electronic lists by topic or of specific searches are available on request (robin.hide@anu.edu.au). One element of this database – an annotated bibliography on the subject of pig husbandry in PNG – has been published (Hide 2003).

Other electronic sources

Increasingly, the internet provides a powerful means to search for information. A huge amount of information is now available on the websites of organisations and institutions. Google or other internet search engines will find these sites if sensible keywords are used. Search engines will also provide the web addresses of particular journals. A search engine designed to assist researchers, Google Scholar, will access author, title and subject listings, including citations of papers in other journals, which can often help locate a particular paper.

Bibliographic software like EndNote makes it possible to manage large numbers of references. Many journal websites allow a full reference and abstract to be downloaded in a format that EndNote recognises. A very important tool for scientific research is access to full text digital copies or images of papers from the websites of particular journals and archives. Access to digital copies is often restricted and usually a fee is charged, unless the access is made through an institution that has paid the access fee in advance.

Access to most journals is not presently available in PNG. However, in 2008, the National Research Institute, National Agricultural Research Institute, Office of Higher Education and the six PNG universities established the PNG Academic and Research Network (PNGARNet). PNGARNet uses satellite communications to overcome problems created by the geographical isolation of these institutions from each other by providing high speed internet connections. If funding becomes available, the members of PNGARNet will provide access to their individual library catalogues and full text journal databases.

Another source of references to information on PNG (but not the information itself) is web-based library catalogues.[3] Many library catalogues can be accessed from outside the institution that supports them. The Australian National Library is a good example <http://catalogue.nla.gov.au/>. Most Australian university library catalogues can be accessed by external users.

How to use this book

Some readers may choose to read this book from the start to the end, while others will refer to a particular section that is of interest to them. However, information on a particular topic may be found in a number of places. The book contains a comprehensive index and we encourage readers to use the index to find all the references to information on topics of interest.

[3] For an overview of libraries in PNG, see a paper by John Evans titled *Libraries in Papua New Guinea*. An early version of this paper can be accessed on the web at <http://www.pngbuai.com/000general/libraries/library-development/png-libraries/Encx-libraries-png-1.html#national-archives>.

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Twenty myths about Papua New Guinea agriculture

R. Michael Bourke and Bryant Allen

A myth is a popularly held belief that has no basis in fact. A great deal of misinformation exists about agriculture in PNG. Some of it is repeated often in official reports, newspaper articles, letters to newspapers and in public statements by prominent people and thus becomes a myth. One of the aims of this book is to present facts about PNG agriculture, with the supporting evidence, so that those who debate policy and make recommendations for change can base their arguments on established truths, instead of myth.

Myth No. 1 Food production is not keeping pace with population growth.

In almost all places in PNG, villagers have increased production as population has grown so that the food supply has been maintained. The rate of increase of locally grown foods has varied over time. For example, in the period 1998 to 2005, production of staple foods for subsistence and sale increased faster than population growth and imports of rice and wheat per person declined (Section 2.7). In a limited number of locations locally produced food has not kept pace with population growth and people are either short of food or sell other produce to buy food (see Box 5.3).

Myth No. 2 PNG is a food-deficit country.

This myth is based on an FAO definition that labels a country as 'food-deficit' if imports of grain exceed exports of grain. PNG does not export grain. However, an estimated 83% of food energy and 76% of protein consumed in PNG comes from locally grown foods (Figure 2.1.1). PNG exports other foods including palm oil, copra oil, coffee, cocoa and tea. The FAO definition is not questioned in PNG but is repeated inside PNG and at international conferences, possibly in order to try to attract aid funding.

Myth No. 3 Papua New Guineans live mainly on imported rice.

This myth is believed by many urban people for whom imported rice is their most important food. But it is not true for most people. Imported rice provides an estimated 9% of food energy in PNG (and wheat-based foods a further 5%) (Figure 2.1.2). Locally grown staples provide an estimated 68% of food energy, with sweet potato by far the most important of those crops (Figure 2.2.2). Papua New Guineans consume about 30 kg of imported rice per person per year. This can be compared with their annual consumption of over 500 kg of root crops, banana and sago.

Myth No. 4 Imports of rice are increasing rapidly.

This myth derives from the 1960s and 1970s, when rice and wheat imports were increasing every year and projections of the 1970s trend caused alarm. But per person consumption of rice slowed greatly in the 1980s and actually fell from 34 kg/person/year in the mid 1990s to 27 kg/person/year in 2001–2005. The consumption rate has increased slightly from 2006 as the economy has recovered and rural people have more money to spend on 'luxury' foods.

Myth No. 5 The Australian Administration did not promote rice production in PNG and Australians are attempting to stop local production to protect the Australian rice industry.

From the 1950s to the 1970s the Australian Administration invested significantly in attempts to produce rice, with very limited success (Section 2.5). Increased production of rice, based on the idea that rice imports should be replaced by locally grown rice, has been promoted by many individuals and organisations from the 1950s to the present. Despite considerable effort and financial investment, very little rice is grown in PNG, with annual production a minute fraction of the production of root crops, banana and sago (Table 2.2.1) and a tiny proportion of the amount of imported rice. Rice has not been widely adopted as a cash or subsistence crop in PNG for a number of reasons. The most important is that growing rice for sale results in poor returns to labour relative to other possible activities, such as growing coffee, cocoa or sweet potato (Table 5.20.1). As long as these conditions prevail, there is little potential for expanded rice production.

Myth No. 6 During the 1997–98 food shortages, Australia saved many Papua New Guineans from starving to death, with an emergency famine relief program.

In 1997–98 a countrywide drought and repeated frosts in the highlands completely disrupted some food production systems and severely reduced others (Section 1.6). In 1997, rice imports increased by 66 000 tonnes or about 40% more than the previous year. Most of the additional rice (75%) was sold through retail outlets. This rice was purchased by rural villagers and their urban-based relatives with cash earned from wages, from savings, or from selling export cash crops, fresh food and pork meat. The remainder was purchased by the PNG Government (8%), the Australian Government (4%), and other donors. Rice and other food was delivered by the Australian Defence Force to people in remote areas. If this had not been done, many of these people would probably have died. But the majority of rural Papua New Guineans and their urban-based *wantoks* saved themselves.

Myth No. 7 Imported meat, particularly lamb flaps from Australia and New Zealand, is increasing rapidly in volume.

Consumption of imported meat increased in PNG until 1994. From 1994 the quantity of imported meat eaten per person has fallen by almost two-thirds (Figure 2.9.1). When the kina fell in value relative to other currencies, imported foods became more expensive in PNG and people chose to reduce the amount of meat eaten. Consumption of imported mackerel fish has also decreased (Figure 2.10.1). This has been replaced to some degree by increased consumption of tuna, which is caught in PNG waters and canned onshore.

Myth No. 8 Lamb flaps are an unhealthy food.

Lamb flaps have a high fat content. Consumption of too much animal fat, including lamb flaps, is not good for people's health. However, many rural people eat very little animal fat (and vegetable oil) and consumption of a small amount of fatty food, such as lamb flaps, from time-to-time, is good for people's health. Furthermore, most rural people do hard physical work every day and so use the fat from lamb flaps as energy. Most rural diets are also very low in protein and lamb flaps provide protein. Most urban people, on the other hand, do little physical exercise. They would be healthier if they ate less fatty foods, including lamb flaps. So the idea that consumption of lamb flaps is unhealthy is basically true for most urban people, but is not true for most rural villagers who live an active lifestyle.

Myth No. 9 PNG agriculture has not changed for thousands of years. The practices and crops that are used today are traditional and unchanging.

Agriculture in PNG has a long and diverse history that is characterised by a high degree of innovation and openness to change on the part of Papua New Guineans. New crops have been adopted and old ones discarded or their importance has been reduced (Figures 3.1.2, 5.2.3). As well, many new techniques have been adopted or invented, such as composting, planting tree in fallows and crop rotations, particularly as people have intensified land use in response to population increase (Sections 3.6, 3.7). The introduction of sweet potato into the highlands about 300 years ago resulted in many changes in production techniques and in highland societies. The rate of change has increased in the past 140 years (see History of agriculture).

Myth No. 10 PNG has an abundance of high-quality land for agriculture and any tropical crop will grow well anywhere in PNG.

Only a quarter of the PNG landmass is used for agriculture (Table 1.2.1). The rest of the landmass is unsuitable for agricultural production because it is too steep, too high in altitude (too cold), rainfall is very high, or the land is flooded every year (Sections 1.5, 1.7, 1.9, 1.11). About 63% of the land used for agriculture in PNG is on mountains and hills (Section 1.10). Only 7% of the land area is classed as high or very high quality for agricultural production, with a further 20% of moderate quality (Section 1.12).

Myth No. 11 With the exception of oil palm, production of export cash crops is static (sometimes expressed as: production is the same now as it was in 1975 at Independence).

Production of most export cash crops, except copra, has increased over the past 30 years (Table 5.2.2). Production *by plantations* of coffee, cocoa, copra, rubber and tea has declined and this has reduced the overall growth rate. However, production of most export cash crops *by villagers* has increased (Table 5.2.1). From 2002 to 2007 the renewable resources sector (agriculture, forestry and fisheries) grew at 2.9% per year, which is a little faster than the population growth rate.

Myth No. 12 Women do most of the work in producing food in PNG.

Agricultural work is 'gendered' in PNG, that is, there are tasks which are mostly done by women and those which are mostly done by men. But both women and men contribute labour to food and cash crop production, usually as husband and wife. As well, some men do tasks that are considered mainly women's work and vice versa (Section 6.2). Many more women than men sell fresh food in markets, while more men than women sell export cash crops. For this reason men tend to earn more money from agriculture than women.

Myth No. 13 Villagers have a lot of spare time and it does not matter to them how much labour is needed to produce a certain crop.

One of the most important determinants of whether people will adopt a new crop or practice is the amount of food or money that they get in return for the amount of work they have to do to produce the crop. This applies to both cash crops and subsistence crops (Section 5.20).

Myth No. 14 Agricultural production is seriously constrained by customary land tenure arrangements.

Virtually all food crops, betel nut, vanilla and most coffee, cocoa, copra and rubber in PNG is grown on customary land. It is difficult but not impossible to access large areas of land for plantations. Since the mid 1990s, all increases in agricultural production for both smallholders and plantations have been on customary land. Internal migration is significant and many people can access land for agriculture where they settle (see Section 1.4). People are moving from poor agricultural environments to better ones, where the population density is greater (Figure 1.12.4). Many settlement schemes, where settlers have registered title to their land, have been economically unsuccessful (Section 6.7). Similarly, plantation production of all export cash crops, except oil palm, has declined for the past 30 years (Table 5.2.1). There are a number of reasons for this, but having a registered land title did not solve the problems of the plantation sector.

Myth No. 15 There are few roads in PNG and this reduces agricultural production.

More than half of the total population live within 5 km of a national road and a further 10% live within 10 km of a national road. Considerably more also live near a provincial or district road (Section 6.9). When roads were built in PNG, they usually went through the most densely populated places. This myth is fuelled by the fact that Port Moresby is not connected by road to any province, other than Central and Gulf. Unfortunately it is now true that many rural roads and bridges have not been properly maintained and many are impassable in wet weather. This is a significant limitation on agricultural production.

Myth No. 16 There is little information about PNG agriculture with which to develop sound policy, or for planning.

A large amount of information exists on the environment and agriculture in PNG, significantly more than for most other developing countries. The purpose of this book is to bring much of that information together in one place and to indicate where more can be found. Much more remains to be learned, and there are gaps in the knowledge of important topics, such as how many hours of labour are needed to grow particular crops, or which crops are best suited for PNG's different environments. But much is already known about PNG agriculture. (Also see Sources of information about PNG agriculture, page xxv.)

Myth No. 17 There is significant potential to export fresh food to New Zealand, Australia and South-East Asia.

There is very little potential to export fresh food from PNG because of quarantine issues (including a serious fruit fly problem), poor presentation of food, expensive and unreliable air and sea transport and lack of price competitiveness (Section 5.3). Limited possibilities for certain niche markets exist, but many obstacles remain. In contrast, there is significant unrealised potential for expanded sale of fresh food within PNG. Certain indigenous edible nuts, such as *galip, karuka* and *okari*, have considerable potential as export crops.

Myth No. 18 Global climate change is now causing significant problems for many people on very small islands.

Sea level rise, temperature increases, higher rainfall and possibly a greater incidence of extreme climatic events have the potential to cause significant problems for people in many locations in PNG, including those living on very small islands (Section 1.8). Some crops are now bearing at higher altitudes in the highlands because of higher temperatures. But overall the impact of climate change has been relatively small so far. Some problems attributed to rising sea levels are caused by overpopulation (Carteret Islands in Bougainville Province) or sinking land associated with geological activity (Duke of York Islands in East New Britain Province).

Myth No. 19 There is no poverty in rural PNG because there is plenty of food to eat.

There is significant poverty in rural PNG where one million people live in severe poverty (Section 6.10). In PNG poverty is heavily influenced by where people live. 'Poor places' are overwhelmingly rural (94% of poor people live in rural areas). In these locations, carbohydrate food is generally sufficient, but protein, fats and oils are not. Cash incomes are very low so people cannot buy foods that could increase protein in their diets. Health and education services are poor. As a result, life expectancy is short; many infants die before they are one year old; and all measures of health, education and life outcomes are among the worst in the Asia–Pacific region.

Myth No. 20 Poor governance of agricultural institutions does not matter because rural people grow their own food and look after themselves.

A number of the bodies that govern the production, purchasing, processing and marketing of PNG's cash crops have seriously disadvantaged producers by interference in their management by politicians, the appointment of people who do not have the skills to be effective managers and by some very bad policy making (Section 6.4). The best outcomes for PNG producers have occurred when government has stayed out of marketing and exporting, and has regulated in favour of village producers. An example of poor governance affecting marketing is the collapse of chilli exports in 1982, despite a large increase in prices. This was caused by marketing problems with provincial government buying systems (Figure 5.15.1). An example of how good governance has a positive influence on exports is the increase in exports of tuna and increased revenue to PNG in the late 1990s, following the establishment of the National Fisheries Authority and that body's proper regulation of PNG fisheries (Figure 5.9.2).

Introduction

R. Michael Bourke and Bryant Allen

Agriculture is the most important activity carried out by the vast majority of Papua New Guineans. For most people, agriculture fills their lives, physically, culturally, economically, socially and nutritionally. Yet agriculture is the most undervalued and misunderstood part of PNG life (see Twenty myths about PNG agriculture, page 1). The reasons for this are partly because mineral and oil exports make PNG comparatively wealthy for a developing country; partly because agriculture is practised in the countryside, away from towns, and is therefore largely 'invisible' to urban people and international visitors; and partly because agriculture is viewed as not being 'modern'.

However, as this book shows, agriculture feeds most Papua New Guineans, houses them, provides a significant amount of food to townspeople and earns a significant amount of foreign exchange. By doing these things, agriculture provides PNG with a social, economic and political stability which has meant that, despite sometimes poor economic management, the country has been able to weather a number of economic and political crises. Furthermore, agriculture will continue in this role, long after all the minerals and oil have been dug up and exported.

The primary purpose of this book is to demonstrate how important agriculture is to PNG and to provide the knowledge that will enable policy makers to make sensible plans for it, within the PNG economy. For a developing country, PNG is rich in information for planning, but most of it is not easily accessible to those who need it. This book was initially conceived to bring this 'lost' information on PNG agriculture together in a single publication where it would be easy to access. It began as a compendium of statistics but has evolved into a comprehensive book of 72 sections on PNG agriculture and related topics. The number of sections alone demonstrates how agriculture pervades almost every aspect of life in PNG.

Sections include information about population; land use; climate and other aspects of the physical environment in which agriculture occurs; overviews of subsistence food production, with detailed descriptions of production techniques and the most important food crops; descriptions of cash crop production for both domestic and export markets; agriculture in the broader economy; and a series of papers on agricultural development, policies and governance. An overview of 50 000 years of agricultural history in PNG follows this introduction.

An outstanding aspect of this book is the emphasis it places on village agriculture, the most important part of PNG agriculture. It provides details that have not been previously available on subsistence food production systems; on the informal sector that provides most of the marketed fresh food, betel nut, firewood, fish and other products; and on all of the major and minor cash crops, with new analyses and datasets, many of which contain data runs over 40 years long.

The book has a dual focus: food production and cash income. Almost every section relates to how people manage the environment, the production and the marketing of the commodities they produce. The book is dedicated to the village women, men and children who are the skilled agriculturalists of PNG and who produce all of the fresh food in the country as well as most of the export cash crops and the domestic animals.

Agriculture in Papua New Guinea

Subsistence food production is the most important part of PNG agriculture. It provides most of the food consumed in the country – an estimated 83% of food energy and 76% of protein (Figure 2.1.1). Its importance only becomes apparent when a rare partial failure of food production occurs, as happened in the very severe drought and frosts of 1997 (Section 1.6). People's sustenance also comes from hundreds of food crops, husbandry of domestic animals, fish and locally produced sugar (Sections 2.6, 5.9, 5.10). This is supplemented by imported rice, wheat-based foods, some meat and some fish (Section 2.1).

Cash income is provided by sales of Arabica coffee, fresh food, cocoa, betel nut, copra, oil palm, firewood, tobacco, fish and many minor products including vanilla, rubber, balsa and tea (Section 5.1).

There is a long history of agriculture in what is now PNG, with the first settlers arriving about 50 000 years ago. Agriculture began in PNG at about the same time as it appeared in the Middle East and in China, about 10 000 years ago (see page 10). Some food plants were domesticated in New Guinea and others were introduced from Asia and other Pacific islands. In the 1700s, new crops began to reach PNG from the Americas and one, sweet potato, has become PNG's most important crop. Many new food and potential cash crops were introduced during the colonial period, from the early 1870s onwards. A feature of the long history of agriculture in PNG is the careful adoption of some new crops and the rejection of others. It is also characterised by innovations in the management of land including draining, fencing, tree planting, composting, soil erosion control and mounding. Many of these changes have been associated with the intensification of land use, in which more food is produced from the same area of land (Sections 3.6 to 3.12).

Influences of global trends in 2007–2008

Evidence is building that fundamental worldwide changes are occurring that go beyond global climate change, and which will pose multiple challenges for agriculture everywhere. Land once used to grow food is growing biofuels; the demand for many products has increased as the economies of China and other rapidly developing nations grow; agricultural land is being lost to urbanisation and industrialisation; fertilisers and herbicides are becoming more expensive; surface water is being reduced in many locations; soil nutrients are being lost; pest and disease problems are increasing; a neglect of agricultural research is reducing technological solutions; marine harvests are declining; and prolonged droughts exist in a number of countries, possibly associated with global climate change. As a result, the prices of rice, wheat, corn (maize), vegetable oil, dairy products, meat and fish have all increased markedly in 2007–2008.

These global changes pose challenges for PNG agriculture producers and consumers, including much higher prices for imported foods. At present the PNG economy is benefiting from these changes because prices of agricultural commodities that are linked to crude oil have risen sharply in recent years, including palm oil, copra oil and natural rubber. The use of fertilisers and herbicides in PNG agriculture continues to be negligible, with most villagers using little or no inputs into production other than their land and their labour (Section 5.19).

The increase in exports of marine products, mainly tuna (Figure 5.9.2), round logs (Figure 5.8.3) and palm oil from PNG (Figure 5.7.4) is the outcome of higher global demand. The changing global economy is reflected in the greater proportion of logs and balsa from PNG exported to China and other emerging economies in Asia (Figures 5.8.4, 5.13.2).

As this book goes to press in late 2008, global financial markets are in turmoil. This is likely to have far-reaching consequences for the global economy, but much remains unknown. Papua New Guinea rural producers will be affected by these changes, but will be largely sheltered by subsistence food production and their limited dependence on external inputs.

Strengths of PNG agriculture

PNG agriculture has many strengths. Firstly, by providing most of the food consumed within PNG, it imparts great stability to the nation. Agriculture is also the main source of cash income for a great majority of people. People use money to better their lives, including supplementing protein-poor diets, building better houses, educating their children and accessing medical services. Most rural people are employed as producers, processors or intermediate traders in agriculture. As well, there are vigorous informal businesses where people grow, transport, trade and retail fresh food, betel nut, firewood, fish and other commodities (Sections 5.1, 5.17). Agriculture also provides 17% of PNG's exports by value (Figure 5.2.1).

Agriculture is a major contributor to development within PNG. A vibrant cash crop component exists in both the formal and informal sectors, in almost all of the more-developed locations. In contrast, the least-developed parts of PNG, where most people are poor, are characterised by subsistence food production only.

A number of environmental factors severely constrain agriculture in PNG, including excessively high rainfall, steep slopes, inundated land and extensive cloud cover. Villagers have a detailed understanding of the relationship between crops and the environment (Section 1.13). More important than a good physical environment, however, is the energy, drive and adaptability of the people in more than one million rural households. They respond to new opportunities, including higher prices and better returns to their labour (Section 5.20). They form the core of what is a largely unrecognised significant private sector group.

Other parts of the private sector consist of people involved in trading and processing commodities for the domestic and export markets. Thousands of people are involved in trading and transporting betel nut alone, as it is moved from lowland locations to the highlands, where it does not grow, and to urban centres and mines. A few small companies participate in the formal economy, trading and processing produce. A number of large firms grow, buy, process and export oil palm, sugar cane, coffee, cocoa, copra, rubber and tea.

Villagers are often portrayed as unresponsive to price or market messages. The devaluation of the PNG currency in the late 1990s (Figure 4.1.1) is a clear demonstration that this is false. Large increases in the prices for many goods as measured by the consumer price index occurred in the late 1990s (Figure 4.2.1), including imported rice (Figure 4.3.3) which, in turn, led to an increase in the price of marketed sweet potato (Figure 4.3.1). This was also a time of low returns for coffee in the highlands (Figure 5.4.3). Many highlanders responded to the increased price for sweet potato and the reduced price of coffee by growing more sweet potato for sale in urban markets. The increase in production resulted in lower prices for consumers, so that sweet potato became more competitive compared with imported rice, leading to increased consumption of sweet potato. A similar response is occurring in 2008 following rapid increases in the price of rice and other imported foods.

Another strength of PNG agriculture is the customary land tenure system (Section 6.1). Individuals and companies who wish to access large areas of land for agricultural development can be frustrated by customary tenure, but the system is sufficiently flexible to accommodate increasing population and internal migration (Sections 1.1, 1.3, 1.4). It has been argued that economic development will not occur unless all land is privatised and registered to individuals, but individual titles to land on settlement schemes has often resulted in poor economic outcomes (Section 6.7). Nor has the holding of a title helped the plantation sector, where production of all export cash crops except oil palm has declined over the past 30 years (Table 5.2.1; Figures 5.4.4, 5.5.2, 5.7.5, 5.11.3). PNG does not have the administrative capacity to survey customary land, identify customary owners, settle the myriad disputes that would result, and issue titles, let alone record the thousands of changes of ownership that will occur. Only where uncertainties in tenure are causing real problems, such as in the peri-urban areas of the larger towns, should attempts be made to interfere with customary tenure.

Marketing systems for oil palm, coffee, cocoa and copra are efficient and return to growers a reasonable share of the international market price (Section 5.21). Marketing systems are less efficient for vanilla and most domestically marketed produce, particularly fresh food (Sections 5.3, 5.14).

Challenges and constraints

This book identifies a number of significant challenges and constraints which presently limit the potential of agriculture in PNG. If the sector is to achieve its full potential, these will need to be addressed by the PNG Government and private sector, supported by international donors. The major constraints are:

- Pressure on land associated with rapid population growth, particularly in parts of the highlands and on small islands (Section 1.3). This is affecting soil fertility and the ability to grow food.
- Poorly maintained transport infrastructure, particularly roads and bridges (Section 6.9).
- Limited new technology being generated from research. Some commodities, particularly palm oil and sugar cane, are supported by excellent research, but most commodities are not adequately supported, including subsistence and marketed fresh food. Research is frequently focused on a crop, rather than the agricultural system of which it is a part.
- Research capacity directed at commodities that have little or no chance of expanding or being adopted, including rice, wheat and pulses.
- Very limited effective outreach and agriculture extension capacity. Despite the availability of a moderately large body of information which would advantage producers, little of this is effectively communicated to them.
- Climate change as a significant long-term challenge, particularly rising sea levels, greater rainfall, increasing temperatures and possibly greater frequency of extreme climatic events (Section 1.8).
- Mismanagement of the national economy, poor performance of institutions involved in the governance and administration of agriculture, and poor policy making. This includes policies that result in distortions of the terms of trade and large movements in the currency exchange rate (Sections 4.1, 6.3, 6.4).
- Insufficient involvement of women in some aspects of agriculture, particularly trading (Section 6.2).
- An HIV/AIDS epidemic, which will severely affect agricultural labour supply in some places (Section 1.1).
- Inadequate security for people and property.
- Insufficient access to credit for intermediate traders.
- Inadequate attention to quality control for some commodities, particularly coffee, fresh food and vanilla.
- Poor communication among growers, middlemen, processors and retailers in the production and marketing chain.
- Insufficient attention given to marketing and promotion of PNG produce.
- Severe poverty for about a sixth of the population, which limits their ability to participate in the formal economy (Section 6.10).

Future focus for research and development

The greatest returns to investment in PNG agriculture will come from research and development in the following components of PNG agriculture:

- Subsistence food production, particularly sweet potato; agricultural system management; soil fertility maintenance; and pest and disease management (Part 3).
- Domestic marketing of food, particularly root crops and certain fruit, including mandarin, mango, mangosteen and rambutan (Section 3.3).

- Major export tree crops of coffee, cocoa, copra and oil palm (Sections 5.4, 5.5, 5.6, 5.7).
- Minor export crops of rubber, balsa and certain spices (Sections 5.11, 5.13, 5.14, 5.15).
- Fuelwood and hardwood timber species, grown in plantations or in village plots (Section 5.8).
- Edible nuts for domestic and export markets, notably *galip*, *karuka*, *okari*, *pao* and sea almond (Section 3.4).
- Domesticated animals, particularly pigs, chickens, cattle and goats (Section 2.6).

Currently there is investment or interest in a number of new uses for cash crops. For export these include biofuel from cassava, jatropha, castor, corn and coconut; bamboo for edible shoots and timber; sago starch; sandalwood; kava; cashew nuts; and organically certified essential oils from spice plants. Village plots of timber for fuelwood, construction, pulp and hardwood; peanuts; *galip* nuts; noni; and prawn farming are being investigated for both the domestic market and for export. Cut flowers could be grown for the domestic market.

Many of these have good potential. Success will depend on a number of factors, particularly markets, prices and returns to labour or capital investment as well as the removal of at least some of the constraints listed above.

There are proposals for the development of a number of other agricultural commodities, including fresh food for export; processing food for the domestic market; and local production of rice, wheat and pulses to replace imports. We believe that poor returns and other limiting factors mean that these proposals have little or no realistic chance of success. This assessment is based not only on returns to labour and capital investment, but also on a long history of past failures.

Agriculture in PNG has a long and dynamic history in which the outstanding feature has been the willingness of villagers to adopt new crops and to change technologies. Changes in staple foods (Figure 3.1.2) and export cash crops (Figure 5.2.3) over time demonstrate this willingness. Many exciting new possibilities exist for further development of food and cash crops in PNG, but it is important to learn from the past and trust the judgements of village producers. Their willingness to change and develop in the past must be placed alongside their refusal to adopt crops and ideas for which they can see no future. Much of the information in this book was gathered from villagers in every district in PNG. Their knowledge and their needs must be acknowledged if PNG agriculture is to continue to grow.

History of agriculture in Papua New Guinea

R. Michael Bourke

Introduction

The history of agriculture in PNG is about 10 000 years old. This history is reviewed here in the context of 50 000 years of human occupation of the Australia – New Guinea region.[1] More is known about what has happened nearer to the present, especially since 1870, than about the distant past. Much of the early history (prehistory) of PNG was unknown until about 50 years ago, but since 1959 there has been a lot of research on the prehistory of PNG, with a major focus on agriculture. However, this is a rapidly evolving field of study and our understanding of the history of agriculture in PNG is still incomplete. The information that is summarised here will be expanded and modified by future research.

Historical evidence is reviewed in a number of periods: the arrival of humans in New Guinea some 50 000 years ago; the beginnings of agriculture about 10 000 years ago; the appearance of Austronesian-speaking people from island South-East Asia about 3500 years ago, bringing with them more domesticated crops and animals;[2] the introduction of sweet potato about 300 years ago; permanent settlement by Europeans and other outsiders, with many introductions of plants and animals after 1870; and the period of rapid social and economic change that commenced about 70 years ago in 1940.

The peopling of New Guinea

When the first humans came to New Guinea about 50 000 years ago the climate was very different from now. Worldwide, temperatures were lower, the polar ice caps were larger, glaciers were more common, and sea levels were lower. As a result, the South-East Asia mainland extended as far east as Bali and Borneo to form a landmass that is known as Sunda. The Asian mainland (Sunda) and New Guinea were always separated by ocean but, at that time, New Guinea was not an island, but formed the northern part of a large continent that also included Australia and Tasmania, known as Sahul (Figure 1). The Bismarck Archipelago and the Solomon Islands chain have always been separated from the Sahul continent by ocean.

The world climate started to warm from about 18 000 years ago. The sea level began to rise from the melting of ice caps and glaciers and the tree line became higher. The extensive low-lying plains between New Guinea and Australia were flooded. By 10 000 years ago, only a narrow strip of land linked southern New Guinea with the Australian mainland. Around 8500 years ago this land bridge was broken

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1 Prehistorians do not agree how long humans have occupied the Sahul continent (Australia, New Guinea and Tasmania). The figure of 50 000 years used here is a compromise between the shorter time period of about 45 000 years argued by some scholars and the longer one of 50 000–60 000 years argued by others.

2 See box on page 11 for a definition of domestication.

when Torres Strait became flooded and the northern part of the great Sahul continent became the island of New Guinea, with a coastline similar to the present.

The first people to settle the Sahul continent are likely to have come in small groups. They would have made scattered landings on the coastline following earlier movements from the Asian mainland via the eastern islands of the Indonesian archipelago. Following the initial colonisation, human settlement spread to different parts of what is now PNG.

People probably reached the islands of New Britain and New Ireland by 40 000 years ago, soon after the initial colonisation of the Sahul mainland. By 28 000 years ago there were people on what is now Buka Island, at that time the northern end of a single island that included most of the Solomon Islands. The trip from New Ireland to Buka required some time at sea without view of the target land. Manus was settled by at least 20 000 years ago. Colonisation of Manus involved an open sea crossing of more than 200 km, of which 75 km would have been out of sight of land. Human settlement in the Pacific islands extended as far as the end of the Solomon Islands until about 3500 years ago.

Definitions of terms

Archaeology. The scientific study of a prehistoric culture by excavation and description of its remains.

Bismarck Archipelago. The islands of Manus, New Ireland and New Britain and smaller nearby islands, north-east of mainland PNG.

Domestication. The process whereby people transform a wild plant or animal population into one with more desirable characteristics, usually with an edible product such as a grain, tuber, fruit or nut (in the case of plants). This is done by selection and propagation of plants or animals with the desired characteristic.

Glacier. A river of ice. Small glaciers still exist at high altitudes in west New Guinea (Indonesian Papua), although these are disappearing as the climate warms (see Section 1.8). There were a number of glaciers in the mountains of east New Guinea up to about 18 000 years ago.

New Guinea. The second largest island in the world (after Greenland), lying just south of the equator. It is split into two national units. The eastern half is part of Papua New Guinea, an independent nation, while the western half (west of 141° E longitude) is the Indonesian province of Papua, formerly known as Irian Jaya. The term New Guinea is used here to refer to the island, not to a political unit.

Papua. This is a confusing term as it has a number of meanings. Papuan languages are a group of related languages spoken mainly on the island of New Guinea, but also by some groups in New Britain, New Ireland, the Solomon chain and the Timor and Halmahera areas of east Indonesia. Papua is the current name of the Indonesian province that occupies the western half of the island of New Guinea. It is also the name of the former Australian colony, now known as the Southern Region of PNG; and thus it has been incorporated into the name for the nation of Papua New Guinea.

Prehistory. The history of humans in the period before events were recorded in documents, known mainly through archaeological research.

Solomon Islands. A chain of islands lying south-east of New Britain, extending from Buka to San Cristobal. The two larger north-west islands (Buka and Bougainville) lie in PNG; the others in the political state of Solomon Islands. The term is used here in a geographic rather than political sense.

Tree line. The distance above sea level, or altitude, above which trees do not grow because the temperature is too low. In PNG at present the tree line is around 3800 m above sea level.

The earliest indications of human activity in the mountains of New Guinea are thought to be 35 000 years old and are evidence of disturbance of the vegetation by burning. This may have been caused by hunting and exploitation of seasonal foods, especially pandanus nuts, rather than long-term occupation. From about 18 000 years ago, as the climate became warmer, the vegetation in the highlands changed and there was greater use of the highland valleys by people.

Around 3500 years ago a group of people came to the New Guinea area. They were pottery-making agriculturalists and possessed what archaeologists call the 'Lapita culture', named after a style of pottery that they made. Over the next 500 years 'Lapita' people moved beyond the limit of previous settlement at the end of the Solomon Islands and reached New Caledonia, Fiji, Tonga and Samoa. They spoke languages known as Austronesian, which may have originated in Taiwan. These languages are now found

Figure 1 The Sunda and Sahul landmasses at about 50 000 years ago when people first came to Sahul.
Note: Some modern islands were connected to the two large landmasses and others, such as New Britain, New Ireland and the Solomon chain, were always separate. Source: Cartographic Services, ANU.

over a very large area in the Pacific, Indonesia, parts of mainland South-East Asia, and Madagascar in the western Indian Ocean. In PNG they are much better represented in the Bismarck Archipelago and other islands than on the New Guinea mainland, where they are scattered around the coast, particularly in the north and east. Austronesian speakers later spread throughout the Pacific as far as Easter Island, New Zealand and Hawaii. Some of their Polynesian descendents came back to settle on small islands in the New Guinea region within the last 1000 years.

The history of the New Guinea region is made up of many movements of people and Papua New Guineans are heirs to a long and varied genetic, linguistic and cultural history. Most details of the early settlement history are unknown and may never be known. The early colonisation of Sahul would have been made up of small independent movements from different starting points to different places on the coast. Similar movements would have continued after initial colonisation, as illustrated by the transport of plants, animals and raw materials described below.

Subsistence for the first settlers (50 000 to 10 000 years ago)

The first settlers in New Guinea and nearby islands obtained their food from hunting, fishing and gathering. The animals hunted included giant marsupials, now extinct and possibly hunted out of existence by the migrants. The people would have exploited local plants for food, including sago. It is probable that sago was domesticated by the selection of plants with a high content of starch in the trunk. Human populations were probably very small.

Stone tools, dated to some 40 000 years ago, have been found on terraces on the north side of the Huon Peninsula of Morobe Province. These tools were possibly used to thin, trim and ringbark trees to assist the growth of desirable plants that provided food or to obtain starchy food from sago or cycad trees.

It is likely that very early people started to use trees that had, for example, larger edible nuts, and to cut down trees that had smaller nuts. If this was done over a long period, the best-yielding trees will now dominate the forests where people are living. *Galip* nut (*Canarium* species) provides evidence for this practice. Seed remains of *galip* nut have been dated as early as 17 000 years ago in archaeological excavations in the middle Sepik area. They have been dated at 15 500 years ago on Manus, at 11 500 years ago on Buka and 9000 years ago on New Ireland. It seems that *galip* was domesticated by people on the north coast of New Guinea and then introduced to the Bismarck Archipelago and Solomon Islands.

Edible nuts of one pandanus species (*Pandanus antaresensis*) have probably been used for about 30 000 years, and the high-altitude pandanus nut (*P. brosimos*) was possibly first used about 10 000 years ago. The form of nut pandanus that is common at 1800–2600 m altitude in the highlands now (*P. julianettii*) appears to have been domesticated from *P. brosimos*, possibly about 2000 years ago (see Section 3.4). It is likely that people were domesticating other plants at this time, even before they used agriculture as we now know it. Such plants could have included *marita* pandanus and other nut- and fruit-bearing plants. People may also have been exploiting wild taro plants a long time before the beginning of agriculture: taro starch has been found on stone tools from Buka Island that were used as long as 28 000 years ago.

We also know that people were trading obsidian (a black, glass-like stone formed in volcanoes that was used to make sharp cutting tools) a long time ago. Obsidian from Talasea on the north coast of New Britain first appeared in New Ireland about 23 000 years ago and has been found as far away as Borneo. We also know that people were moving wild animals such as the cuscus and bandicoot from the New Guinea mainland to the islands, with the first movement as early as 23 000 years ago. Presumably, wild animals were transported so they could be hunted for food. The cassowary is the only indigenous animal that has undergone some degree of domestication. People hunt it and rear captured chicks. It is not known for how long people have done this.

The beginning of agriculture (10 000 years ago)

By 10 000 years ago the climate had warmed to modern temperature levels. It seems that people started practising agriculture, at least in the New Guinea area, from about 10 000 years ago. Certainly, from 7000 years ago, the evidence for agriculture is very clear. It is also likely that agriculture was invented in the New Guinea highlands at about the same time as it appeared in other parts of the world,[3] and that the development of agriculture in New Guinea was independent of what happened elsewhere. The evidence comes from a site called Kuk in the upper Wahgi Valley in Western Highlands Province. Extensive research at Kuk over a 30-year period suggests that:

- Plants were being exploited and some cultivation was occurring about 10 000 years ago. Archaeological research has found features that indicate planting, digging and staking of plants, and possibly localised swamp drainage. Taro starch found on stone tools excavated at Kuk that are about 10 000 years old suggests that taro was being planted at Kuk at this time.
- A network of small island beds and associated basins had been constructed by 7000 years ago, so that water-tolerant plants could be cultivated in the basins and those requiring drier conditions could be planted on the island beds.
- Banana was intensively cultivated from 7000 years ago.
- From 4500 to 5000 years ago, swamp gardens were drained by straight line ditches dug at right angles to each other that drained into large channels.

3 Apart from PNG, other centres of early agriculture were the Fertile Crescent of the Middle East and the Yangtze and Yellow river basins of central China, with dates of 11 000 and 9 000 years ago respectively.

Arrival of the Austronesians (3500 years ago)

The arrival of the Austronesians is associated with the appearance in the Bismarck Archipelago of the distinctive Lapita pottery and the first domesticated animals – the pig, chicken and dog. The newcomers were agriculturalists and brought many of their crops with them. Some of these were of the same species of plant that people had domesticated in the New Guinea region. Indeed, some of these crops may originally have been domesticated in New Guinea and carried back into South-East Asia.

European exploration and transfer of crops (late 1400s to 1870)

In the late 1400s, explorers, missionaries and traders from Spain and Portugal, and later the Netherlands, France and England, moved and settled around the globe. They took plants and domestic animals from one region and introduced them to other regions. Many of these plants became important economically in the new places. The production of important food and cash crops is now often greater in locations distant from where the crops were initially domesticated. For example, the most important palm oil-producing area is now South-East Asia (Malaysia, Indonesia and Thailand), but oil palm was domesticated in West Africa. Similarly, wheat was domesticated in the Middle East, but the main wheat-exporting nations are now the United States, Canada, Australia, France and Argentina. Sweet potato was domesticated by people in the American tropics, but today the major sweet potato-producing country is China. Sweet potato is now the most important staple food for people in the western Pacific (Solomon Islands, PNG and Indonesian Papua) and production has expanded greatly in that region in the last 60 years.

This major transfer of plant materials around the world by European explorers and colonists, which has had such a large impact on global agricultural production, occurred in the western Pacific later than elsewhere. Europeans and other travellers made sporadic contact with Papua New Guineans from the early to mid 1500s, but there is no evidence that the early European explorers made any plant introductions into PNG at that time.

A small number of species from the Americas were introduced by Europeans into Indonesia and spread from there to PNG before 1870 (Table 1). The most important of these was sweet potato (see page 17). Another crop of American origin that became important in PNG is tobacco. Tobacco was introduced by Europeans to the Moluccas in eastern Indonesia before 1600, from where it spread to New Guinea. It is likely to have come into PNG at a number of locations. One of these is the Trans Fly area in the south of Western Province, where Moluccan traders probably introduced tobacco when they came to this area seeking dammar between 1645 and 1790.[4] The first written record for tobacco in New Guinea is by the Dutch explorer Schouten in 1616, who saw it on Arimoa Island in north-western Papua (Indonesia). Tobacco diffused through New Guinea over several centuries, but it had not reached south-east New Guinea (Oro, Central and Milne Bay provinces of PNG) by the time of first sustained contact with foreigners from the 1870s.

Lima bean was also probably transported from east Indonesia to New Guinea some time between 1700 and 1870. It had been introduced to east Indonesia prior to 1650. Many villagers in the highlands believe that lima bean was used by distant ancestors, but others say it is an introduction (Table 1).

Cassava is another food crop that was probably introduced into parts of mainland PNG from west New Guinea some time after 1800. People in the western part of PNG, in particular Western and Sandaun provinces, consider it to be a 'traditional' crop. It seems that cassava was introduced directly to some islands by European sailors around the same time.

Bixa, a plant used as a bright red dye and body paint, also reached PNG before 1870. Some villagers consider bixa to be a traditional plant, but others do not. It is likely that bixa seed was also spread from Indonesia, where it had been introduced by Europeans from the Americas (Table 1).

[4] Dammar is a resin that comes from a number of trees, including *Vatica papuana*, which grows in south-west PNG (Swadling et al. 1996:157–65). It was used for lighting, as well as for coating and sealing pottery.

Table 1 Proportion of villagers who consider five crops of American origin to be post-European introductions[a]

Crop	Number of locations surveyed	Post-European introduction (%)	Pre-European introduction (%)
Bixa	32	31	69
Cassava	65	63	37
Lima bean	25	20	80
Sweet potato	52	54	46
Tobacco	52	17	83

[a] These crops were introduced to PNG between 1600 and 1870.

Sources: Extracted from published reports and author surveys in various locations in the PNG lowlands and highlands.

Plants used for agriculture until 300 years ago

Prior to permanent settlement by foreigners in the 1870s, more than 170 plant species were used by Papua New Guineans for food. As well, hundreds of other species provided materials for shade, firewood, medicine, tools, weapons, house and fence construction, decoration, rope, string, food wrappings, bark cloth, dress, personal adornment, canoe and raft construction, and ritual and magic purposes. The most important staple (carbohydrate) foods were taro, banana, sago and yam (Figure 3.1.2).

Many plant species that today provide carbohydrate food, vegetables, fruit and nuts were either domesticated in the New Guinea area or were introduced into PNG thousands of years ago (Table 2). Other species were domesticated in Asia or elsewhere in the Pacific and then introduced into PNG somewhere between several hundred to several thousand years ago (Table 3). Many other minor foods in PNG are likely to have been important in the past, but have been displaced by more recent introductions.

Most of the species listed in Table 3 were domesticated in Asia, but two came from the Pacific. The first is *pao* nut (*Barringtonia procera*), which was probably domesticated in the Solomon Islands and introduced into New Ireland and the Admiralty group relatively recently, perhaps less than 1000 years ago. It was taken by migrants from southern New Ireland to the Gazelle Peninsula of New Britain about 400 years ago. It has spread to mainland New Guinea and elsewhere in New Britain over the past 50 years.[5] Kava was probably also domesticated in the Pacific, in Vanuatu, and introduced before 1870 into a limited number of locations in PNG including the Madang area, some islands off Manus Island, and parts of Western Province (see Section 3.5).

5 Related species (_B. novae-hiberniae_ and _B. edulis_) with edible nuts are found on New Guinea as well as the Bismarck Archipelago, Solomon Islands and Vanuatu.

Table 2 Crops domesticated in the New Guinea area, or very ancient introductions

Staple (carbohydrate) foods	*Oenanthe	**Nuts**
*Banana	*_Pitpit_, highland	*Breadfruit
Coconut	*_Pitpit_, lowland	Candle nut
*Cordyline	*Rorippa	Castanopsis
Kudzu (Pueraria)	*Rungia	_Dausia_
Polynesian arrowroot	_Trichosanthes pulleana_	*_Elaeocarpus womersleyi_
*Sago	_Tulip_	*Finschia
*Sugar cane	Wandering Jew	*_Galip_ (_Canarium decumanum_)
*Taro (_Colocasia_)	**Fruit**	*_Galip_ (_Canarium indicum_)
Taro (_Alocasia_)	*_Bukabuk_	*_Galip_ (_Canarium lamii_)
Taro, swamp	Coastal pandanus	*_Karuka_, planted (_Pandanus julianettii_)
*Yam, greater	Golden apple	*_Karuka_, wild (_Pandanus antaresensis_)
Yam, aerial	Mango (_Mangifera minor_)	*_Karuka_, wild (_Pandanus brosimos_)
Yam (_Dioscorea nummularia_)	*_Marita_ pandanus	*_Okari_ (_Terminalia impediens_)
Yam (_Dioscorea pentaphylla_)	_Mon_	*_Okari_ (_Terminalia kaernbachii_)
Vegetables	*_Parartocarpus venenosa_	*_Omphalea gageana_
*_Dicliptera papuana_	*_Pouteria maclayana_	Polynesian chestnut (_aila_)
*_Ficus wassa_	Raspberry, red (_Rubus moluccanus_)	Sea almond (_talis_)
*Highland _kapiak_	Raspberry, red (_Rubus rosifolius_)	_Sis (solomon)_
Job's tears	*_Ton_	**Stimulants**
*_Kumu musong_		Betel nut, highland
		Betel pepper, highland

Note: Species with an asterisk (*) are likely to have been domesticated by people in the New Guinea area. The other species in this table may have been domesticated in the New Guinea area, but the evidence is less clear.

The adoption of sweet potato in the highlands (about 300 years ago)

Sweet potato was taken from its American homeland by Polynesians who introduced it into many Pacific islands and New Zealand about 1000 years ago. However, it came to PNG from Indonesia. Sweet potato was taken back to Europe from the West Indies after the first voyage in 1492 by Christopher Columbus, an Italian navigator and maritime explorer who crossed the Atlantic Ocean under Spanish sponsorship. Portuguese explorers then took sweet potato to Africa, India and their colony in the Moluccas in eastern Indonesia. From there it was traded by local people into New Guinea. Oral history research from the Tari basin in Southern Highlands Province and archaeological research at Kuk in Western Highlands Province indicates that sweet potato was adopted in the highlands some decades after the major volcanic eruption of Long Island off the north coast of New Guinea. This blanketed the highlands in ash which leaves a record in the soil as well as in oral history (related as the 'Time of Darkness'). The eruption has been dated to 1665. Further oral history research shows sweet potato was traded into the Lagaip Valley of northern Enga from the Sepik area. It may have been adopted into the highlands of Indonesian Papua somewhat earlier than 1700.

Table 3 Crops introduced into PNG from Asia or the Pacific several hundred to several thousand years ago

Staple (carbohydrate) foods
Yam, lesser
Vegetables
Aibika
Amaranthus tricolor
Bean, lablab
Bean, winged
Castor
Coral tree
Cucumber
Ginger
Gourd, bottle
Gourd, wax
Lemon grass
Fruit
Malay apple
Rukam
Nuts
Pao (*Barringtonia procera*)
Stimulants
Betel nut
Betel pepper, lowland
Kava

Note: Kava was probably domesticated in Vanuatu. *Pao* was probably domesticated in Solomon Islands. The other crops in this list most likely came to PNG from Asia.

Prior to the adoption of sweet potato in the New Guinea highlands, people depended on taro as their main food, supplemented by banana and yam (*Dioscorea alata*). The adoption of sweet potato brought major changes in highland societies. First, sweet potato makes good pig fodder, and can be fed to pigs raw, whereas taro must be cooked.[6] The adoption of sweet potato gave an advantage: people could produce more pigs, thus becoming wealthier than their neighbours. Also, their diet possibly improved. Second, sweet potato will grow at higher altitudes than taro. The adoption of sweet potato meant that people could occupy higher altitude land on a permanent basis. Settlements spread from around 2200 m up to 2800 m above sea level. Third, the adoption of the new crop resulted in significant changes in the social organisation. Some of these changes are known from oral history research in Enga Province.

By the time that Europeans penetrated the highlands of PNG in the 1920s and 1930s, sweet potato was the main food for almost all highlanders. There were some exceptions. West of the Strickland River, in the Oksapmin and Telefomin areas, taro remained the

6 Taro contains crystals of oxalic acid that cause severe irritation to the mouth and throat of humans and pigs. Cooking destroys these crystals and makes taro edible.

most important food. Several groups of people living in the Lamari and Imani valleys south of Kainantu still depended on a mix of taro, yam and sweet potato. People in these two valleys changed to a diet based on sweet potato after about 1980. At the time of contact with outsiders, sweet potato was present at a number of locations along the north coast of New Guinea as far east as the Huon Peninsula. It was not present in the Bismarck Archipelago and Solomon Islands until the early to late 1800s, where it was introduced by European traders and settlers.

Some people in the PNG highlands, for example in the Tari basin, have stories about the time when they did not have sweet potato and taro was their staple food. But most highlanders think that their ancestors have always lived on sweet potato. In fact, it has been the most important food in the highlands only for about 10–12 generations, or 300 years. The changes brought about by its adoption are still occurring today, for example, in the continuing intensification of land use (see Section 3.6).

Settlement by foreigners and introduction of many new crops (since 1870)

The settlement in PNG by foreigners first occurred in the early 1870s. Europeans, Asians and other Pacific islanders settled in many coastal locations,[7] bringing with them new plant species. The Russian scientist Nikolai Miklouho-Maclay lived on the Rai Coast near Madang for several years from 1871. In the same year, the London Missionary Society (LMS) placed teachers on three islands in the Torres Strait near PNG. In the following year (1872), the LMS established stations west of Port Moresby and on the coast of Western Province. Also in 1872, a trading post was established on the Duke of York Islands between New Britain and New Ireland. In 1873, the German firm Godeffroy set up trading stations in Blanche Bay on New Britain. Methodist missionaries established a station on the Duke of York Islands in 1875.

Records of crop introductions are limited, although some early accounts exist. French Marist missionaries introduced a number of food crops to Woodlark Island in Milne Bay Province in 1847, including beans, pumpkin, corn (maize) and watermelon. Miklouho-Maclay introduced pumpkin, watermelon, corn and pawpaw (papaya) to the Rai Coast in 1871 with seed brought from Tahiti. He noted that the pawpaw, watermelon and corn 'became the favourites and were soon introduced in the plantations [gardens] and the villages on the coast'. In 1873 he introduced mangosteen, durian, orange, lemon, coffee and other species with seed from east Indonesia.[8] Methodist missionaries introduced a number of food crops to the Duke of York Islands in 1875, including orange, lemon, lime, custard apple, guava and new varieties of banana. Many of the early introductions in PNG were made by Pacific island missionaries, as well as by Europeans and Asians.

When many of these introductions occurred is not known, but it is known which species have been introduced since 1870. These include hundreds of potential cash crops, as well as fodder plants (grasses and legumes), shade crops, decorative plants and weeds.[9] Many food crops were introduced into PNG

7 Prior to 1870 there were a few scattered and generally short-lived settlements in the New Guinea region. From 1793 to 1794 there was a British settlement at Restoration Bay near Manokwari in west New Guinea. The Dutch made a settlement on the south coast of west New Guinea at Triton Bay in 1828–36. Both locations are a long way from PNG, so it is unlikely that crops introduced by the British or Dutch settlers were transported to PNG, but it is possible. A mission station was established at Guasopa on Woodlark Island in Milne Bay Province by French (and later Italian) Marist Catholic missionaries between 1847 and 1855. The Marists established a settlement on Umboi Island between New Britain and New Guinea in 1848–49. These settlements had limited and local impacts.

8 Villagers at Bongu village and nearby locations still use their version of Russian names for some of the plants and items introduced by Miklouho-Maclay, including watermelon, corn, pumpkin, cucumber, knife and axe. The term for corn (*gugurus*), derived from the Russian word for maize (*kukuruz*), is used elsewhere in coastal Madang Province.

9 For example, the Experiment Station at Rabaul had planting material of 115 species available for distribution in 1926. Most were introduced species and included fruits, vegetables, other food crops, cover crops, fodder grasses and actual or potential cash

after 1870 (Table 4). The Department of Agriculture, Stock and Fisheries introduced more than 2200 varieties of 90 food crop species between 1950 and 1975. Many of these species were already in PNG by then; further introductions were made to identify varieties with superior qualities.[10]

Foreign settlement, particularly the introduction of new crops and cash cropping, resulted in an important new era in PNG agriculture. Some of the new crops were adopted by villagers and had a significant impact on village agriculture. For example, the anthropologist Malinowski, who conducted fieldwork in the Trobriand Islands in Milne Bay from 1915 to 1918, noted that, since the adoption of sweet potato (in the 1890s) and the availability of imported rice, there had not been a famine. Sweet potato, and later cassava, were widely adopted throughout the islands of Milne Bay Province and greatly improved food security. At a village in the Aiyura basin in Eastern Highlands Province in 1980, villagers grew 87 species of food and cash crops. Almost 60% of these (51 species) had been introduced and adopted during the previous 50 years, including some grown in significant quantities such as peanut, coffee, common bean, Chinese taro, corn and pak choi.

Some introduced crops moved inland ahead of European colonisation. Corn was widely grown in Eastern Highlands, Simbu and Western Highlands provinces when the first European explorers and missionaries visited those areas in the 1930s. It was spread by villagers after being introduced to the Madang area by Miklouho-Maclay. The naturalist MacGillivray further distributed corn in Milne Bay in 1849. Corn was present on some other islands when first visited by European explorers in the 1870s. Similarly, some people in the highlands were growing common bean by the 1930s. It also seems to have been introduced into some coastal locations in the 1870s or 1880s and to have spread into the highlands over the next 40–50 years. Another crop that was adopted quickly in the highlands was pumpkin. Villagers in some locations in the Sepik River area believe *kangkong* to be a traditional crop, which suggests that it was possibly introduced to that area some decades before 1870.

Foreign cash cropping (1880s onwards)

Individual foreigners and overseas companies have been involved in PNG agriculture since the 1880s. This history is partially covered in a number of publications and is reviewed only briefly here. Some of the first foreign settlers in PNG came to trade for coconut to make copra. Villagers in many coastal locations in the islands and on the New Guinea mainland responded by planting significantly more palms. Copra was the most important cash crop in PNG from the 1880s to the early 1970s. Foreigners in both New Guinea and Papua produced and exported a wide range of cash crops from the 1880s onwards, generally in small quantities. These included tobacco, cotton, kapok, rubber, cocoa, sisal and coffee. Cattle and rice were grown for the local market. Other agricultural exports collected from natural stands of trees or the sea included ivory nut (the seed of a palm related to sago), sandalwood, bêche de mer (sea cucumber), trochus shell and pearl shell.

Prior to 1940 experimental plantings were made of a wide range of other crops including sugar cane, corn, castor, tea, cinchona (for quinine), teak, oil palm, vanilla, ginger and peanut, with a view to developing export industries. During the 1950s copra remained the most important export crop, supplemented by rubber, cocoa and coffee. Coffee and cocoa increased in significance in the 1960s and 1970s (Figure 5.2.3). Oil palm, tea, tobacco, corn, sorghum and peanut were also grown by individual foreign settlers and large plantation companies. Village cash cropping increased in significance from the 1950s and the plantation sector declined after 1980. Smallholders now dominate production of all cash crops except oil palm (Table 5.2.1).

crops. The cash crops included those producing fibres, oils, spices, rubber, West African oil palm, bixa, coffee and cocoa. There were a number of varieties of some species (Hopkins 1926).

10 Rice (627 varieties) and wheat (272 varieties) accounted for 40% of the varieties of food plants introduced between 1950 and 1975 (Charles 1976). This was part of a significant but unsuccessful research effort by the Department of Agriculture, Stock and Fisheries to make PNG self-sufficient in rice production (see Section 2.5).

Table 4 Some of the food crops introduced into PNG after 1870

Staple (carbohydrate) foods	Pumpkin	Mango (*Mangifera indica*)
Corn (maize)	Radish	Mangosteen
Irish potato	Rhubarb	Mulberry
Queensland arrowroot	Shallot	Naranjilla
Rice	Silverbeet	Nectarine
Taro, Chinese	Soya bean	Orange
Wheat	Spring onion	Passionfruit, banana
Vegetables	Tomato	Passionfruit, lowland yellow
Amaranthus blitum	Turnip	Passionfruit, purple
Amaranthus caudatus	Watercress	Pawpaw
Amaranthus cruentus	Yam bean	Peach
Bean, broad	Zucchini	Persimmon
Bean, common	**Fruit**	Pineapple
Bean, snake	Apple	Plum, Japanese
Beetroot	Avocado	Pomegranate
Broccoli	Brazil cherry	Pomelo
Cabbage, Chinese	Bullock's heart	Pulasan
Cabbage, head	Cape gooseberry	Rambutan
Capsicum	Carambola	Raspberry, black
Carrot	Cherimoya	Rockmelon
Cauliflower	Cumquat	Santol
Celery	Custard apple	Soursop
Chilli	Durian	Star apple
Choko	Elder	Strawberry
Eggplant	Governor's plum	*Suga prut* (highland yellow passionfruit)
Garlic	Granadilla	Tamarillo (tree tomato)
Kangkong	Grapefruit	Tamarind
Kohlrabi	Guava	Watermelon
Leek	Guava, cherry	Watery rose apple
Lettuce	Jackfruit	**Nuts**
Onion	Langsat	Cashew
Pak choi	Lemon	*Macadamia integrifolia*
Parsley	Lime	*Macadamia tetraphylla*
Pea	Loquat	Pecan
Peanut	Mandarin	

Changes in village agriculture since 1940

After 1940 the rate of change in PNG agriculture increased greatly. Factors driving these changes were:

- Population increase and pressure on land. The population of PNG rose from 2.2 million in 1966 to 5.2 million in 2000 (an increase of 138%) (Table 1.1.3).
- Alienation of land in some locations, resulting in increased land pressure. For example, in the Cape Hoskins to Talasea area of New Britain, land was alienated for growing oil palm (see Sections 5.7 and 6.1).
- Cash cropping by smallholders. Crops include cocoa, coffee and coconut (see Part 5).
- Plant diseases, especially taro blight, but also a root rot in Chinese taro.

The first major change since 1940 was the replacement of taro by sweet potato as the staple food in Bougainville and the rest of the Solomon Islands. This occurred because of the devastating impact of taro blight, which was introduced there in the early 1940s. Change did not occur evenly in all parts of the country. On the Gazelle Peninsula of East New Britain Province, for example, major changes in the food crops grown, production techniques used and the adoption of cocoa as a cash crop took place between 1945 and 1965, while in adjacent West New Britain Province the widespread planting of oil palm and changes in the main food crops grown did not take place until after 1970.

The responses people made to the new social and economic conditions include:

- Adoption of new crop species. Production of sweet potato and cassava in particular has expanded greatly since 1940 (Figures 2.2.1, 2.2.3). Other crops that have been widely adopted and become relatively important foods include corn, peanut and Chinese taro. Irish potato has become important above 2000 m altitude.
- Adoption of more productive varieties of some crops, including sweet potato and banana.
- More intensive land use characterised, for example, by shorter fallow periods and longer cropping periods (see Sections 3.6 and 3.8).
- Development or adoption of techniques to maintain soil fertility. These include managing fallow species composition by planting trees (especially casuarina in the highlands); crop rotations, especially of sweet potato and peanut; and green manuring (composting) (see Sections 3.7 to 3.12).
- Development of new agricultural systems by the integration of export cash crops into food crop systems. These systems include coffee–casuarina–food crops in the highlands and cocoa–food crops–leucaena–banana on the Gazelle Peninsula.

Agricultural techniques

Villagers use a variety of agricultural techniques in the cultivation of food and cash crops (see Sections 3.7 to 3.12). These techniques are used in different combinations, depending on climate, soil type, fallow vegetation and pressure on land. Archaeological research provides evidence as to how long some of these techniques have been practised.

- **Stone tools** were used as early as 40 000 years ago. Stone tools were used for clearing trees until the late 1800s, when they were replaced by introduced steel tools. In some highlands locations, stone tools were used until about 1950. In some places stone tools are still used to extract sago starch.
- **Burning** has a very long history in PNG and has been used for clearing land for at least 30 000 years (see Section 3.8).
- **Drainage** of agricultural land is widespread in PNG (see Section 3.12). Field drains have been dug in the highlands to remove excess water from food gardens for 4500–5000 years.

- **Mounding** is a widespread technique in PNG (see Section 3.11) and has been observed from 7000 years ago at Kuk.
- **Fences** are commonly built to exclude domestic and wild pigs from food gardens (see Section 3.12). This technique has not been dated, but presumably it was only adopted after pigs were introduced into PNG about 3500 years ago.[11]
- **Green manuring (composting)** was widespread in large areas of Enga, Southern Highlands and Western Highlands provinces when Europeans first visited the region in the 1930s (see Section 3.11). It is possible that the technique was invented in this form about 150 years ago.[12]
- **Planting trees** in fallow land to improve soil fertility is a technique used in a limited number of locations (see Section 3.10). This technique has increased in importance since the 1920s, but it is not known when it first developed. An examination of swamp deposits in a number of highlands locations has shown that at around 1200 years ago there was a marked increase in the numbers of casuarina pollen grains compared to older levels. This has been interpreted to mean that people began deliberately planting casuarina trees around this time, perhaps to provide timber as natural stands were depleted.

11 Pigs were introduced into the Bismarck Archipelago about 3500 years ago. The earliest record for pigs on the New Guinea mainland is 2000 years ago and the first record for the highlands is 1000 years ago.

12 The practice of placing organic matter in large mounds or beds to form compost was still spreading in recent decades (early 1960s to late 1980s) on the edge of the 'composting zone'. This suggests that adoption of the technique was as recent as the nineteenth century. Given the initial boost that sweet potato would have given to food production, there would not have been a need to adopt such a technique immediately after adoption of sweet potato. Development of the large composted mounds in Enga probably occurred in central or western Enga some years after the initial introduction of sweet potato (Wiessner and Tumu 1998:115).

Summary

People were in what is now the island of New Guinea about 50 000 years ago and in the Bismarck Archipelago and the Solomon Islands around 40 000 and 30 000 years ago respectively. We do not know who the earliest occupants of New Guinea were, nor their relationship to modern populations. The final period of prehistoric settlement is associated with the arrival of Austronesian speakers from island South-East Asia. They entered the Bismarck Archipelago and the Solomon Islands over the period 3500 to 3000 years ago and had a marked influence on the subsequent history of those regions. Austronesian impact on the New Guinea mainland was later, more uneven, largely restricted to the coast and intensive only in particular places. Settlement by Europeans, Asians and other Pacific islanders from 1870 onwards caused major changes in agricultural production.

The very early New Guineans depended on hunting and gathering, but it is probable that they began to manage nut-producing trees to encourage better production. There is evidence from starch grains on stone tools for use of taro 28 000 years ago on Buka Island. It is likely that early migrants domesticated sago, *galip* nut and other native species. Agriculture was invented in New Guinea independently of developments elsewhere in the world but at a similar time to its beginnings in the Middle East and central China.

It is now generally accepted that many of the PNG food crops that were important before 1870 were domesticated in New Guinea or nearby areas, including the Bismarck Archipelago, as well as in Asia. Important foods probably domesticated in the New Guinea area are taro, some yam species, banana, breadfruit, sago, many plants used as green vegetables, and some fruits and nuts. Some species were domesticated in both the New Guinea area and Asia independently. In contrast to the important food crops, the most important domestic animal species – the pig, chicken and dog – were introduced into New Guinea after being domesticated elsewhere.

The indigenous PNG cassowary has been hunted and captured chicks reared in captivity, so it could be said to be partially domesticated.

There is a long but poorly known history of adoption and domestication of new crop species. It is likely that a number of new species were introduced by Austronesian-speaking migrants from about 3500 years ago. The overall direction has been replacement of crops by others that have higher productivity, can cope better with environmental or disease problems, and have superior eating properties. For example, it is likely that people once ate wild yam with poor eating properties. Some of these species were domesticated and the quality of the tubers improved. There are indications that some species of yam, such as *Dioscorea pentaphylla* and *D. nummularia*, are very ancient crops in PNG, perhaps introduced from elsewhere but most likely domesticated in the New Guinea area. Tubers of *D. pentaphylla*, for example, have inferior eating qualities and yields appear to be poor, yet people still grow the occasional plant, probably for its cultural value ('*bilong tumbuna*') rather than for food. It is likely that superior varieties of the greater yam (*D. alata*) were developed and that greater yam became the most important species of yam before the introduction of lesser yam (*D. esculenta*).

Lesser yam is likely to have been a later introduction into PNG.[13] It is agronomically superior to other yam species in PNG, including greater yam, has fewer disease problems, a greater yield per plant and tubers that are more easily prepared for cooking than those of most yam species. More people grow greater yam than lesser yam, although greater yam is not usually an important food (Tables 3.1.1, 2.2.1). *Dioscorea esculenta* is less important for ritual purposes than the other yam species, particularly greater yam. All of this suggests that lesser yam has been adopted because of its ability to provide food energy, while the other species have been retained for different reasons.

The many minor species of green vegetables used in PNG may also be what the ethnobotanist Jacques Barrau calls 'witnesses of the past'. That is, their continuing use tells us that they were once important foods, but have been superseded by superior species. The displacement of older species by ones with superior characteristics has continued into recent times. For example, sweet potato replaced taro as the main food in the highlands about 300 years ago. In the lowlands, food crops of American origin, particularly sweet potato and to a lesser extent cassava and Chinese taro, have displaced the older Asia–Pacific crops of taro, yam, banana and sago (Figure 3.1.2).

The adoption of sweet potato in the New Guinea highlands led to significant changes in the social and economic conditions, as well as allowing settlement at higher altitudes. Sweet potato and tobacco were the first of a wave of new crop introductions. They reached PNG between 300 and 400 years ago. Since permanent settlement by foreigners in the 1870s, a large number of food crops, cash crops, other plant species and domestic animals have been introduced. The new food species, the growing importance of export commodity markets and other social and economic changes have resulted in many important changes to agricultural systems since the 1940s.

Agriculture has had a long and successful history in PNG. The history of agriculture has been one of continuous change and evolution, with the rate of change increasing towards the present. The outcome has been agricultural systems which, despite significant social and economic change in other sectors of the economy, still feed more than 80% of the PNG population. The adoption of new crops and the invention of new techniques to cope with changing environmental conditions, increasing population pressure and social change has been carried out with great skill and imagination. People will have to continue to adapt to different circumstances, including to the HIV/AIDS epidemic, climate change and new economic conditions. There is every reason to believe that they will continue to do so as they have done for the past 50 000 years.

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13 Lesser yam may have been introduced 1000–3000 years ago, but this is a crude estimate. Austronesian migrants possibly introduced it 3500 years ago. However, linguists have not been able to reconstruct a word for this species in Proto-Oceanic, the language spoken by the Austronesian migrants (Malcolm Ross, pers. comm.). This suggests that lesser yam may have arrived in PNG some time after 3500 years ago.

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PART 1

People, Land and Environment

Bryant Allen and R. Michael Bourke

1.1 Total population

The numbers of people in a country and the rate at which they are increasing is a critical issue in any discussion of agriculture and the production of food.

The 2000 National Census gives the total population of Papua New Guinea as 5.2 million. Around 81%, or about 4.2 million of these people live in rural villages (Table 1.1.1). Around 5% live in the National Capital District city of Port Moresby, 8% in other urban areas and 6% in small stations, missions, schools, logging camps and mines, known as 'rural non-village' locations. Only Rwanda, Bhutan, Nepal and Uganda have a greater proportion of people living in rural areas than PNG.

Population growth

Population growth rates are conventionally determined on the basis of the difference between birth rates and death rates. However, almost all births and deaths in PNG are not registered, so estimates of population growth rates must be calculated from census totals. If censuses are flawed for any reason, estimates of growth will also be inaccurate.

The total population of PNG has been increasing at between 2.1% and 3.2% per year since 1966 (Table 1.1.2), with an average rate of growth over this period of about 2.5% per year. At this rate of increase, the total population will double around every 30 years. Every year approximately 105 000 people are added to the population. These people must be fed, clothed, housed, educated and provided with access to health care. If the 2000 population continues to increase at 2.5% per year, it will reach 10.7 million by 2030 (Figure 1.1.1).

Population growth rates between 1966 and 2000 have been highest in the Islands Region at 2.7% per year, with the Highlands and Momase regions growing at around 2.5% per year (Table 1.1.2, Figure 1.1.2). Growth rates in the Southern Region have fluctuated between 1966 and 2000, but overall have been the lowest.

Between the 1990 and 2000 censuses, growth rates in the Highlands and Momase regions appear to have increased significantly to 3.6% per year and 3.3% per year respectively, while in the Islands and Southern regions growth rates have fallen, with almost no growth in the Southern Region. The volcanic eruption in September 1994 at Rabaul, the civil war on Bougainville (1989–1997), and continued growth in the National Capital District will have influenced this pattern, but under-enumeration in the 1990 census has probably inflated the apparent rates of increase in the Highlands Region, as has probable overestimates in the population of Southern Highlands Province in the 2000 census. The 1990 to 2000 increase in the Southern Highlands population is demographically impossible, particularly in light of the known out-migration which is occurring from this province (Figure 1.4.3). The increases are restricted mainly to the central part of the province and suggest errors in the 2000 census data.

Table 1.1.1 Rural, rural non-village, and urban populations of PNG, 2000

Province	Rural	%	Rural non-village	%	Urban	%	Total
Western	107,837	70	12,445	8	33,022	22	153,304
Gulf	92,265	86	3,620	3	11,013	10	106,898
Central	157,058	85	21,165	12	5,760	3	183,983
National Capital District	0	0	0	0	254,158	100	254,158
Milne Bay	188,334	90	9,327	4	12,751	6	210,412
Oro	106,288	80	15,406	12	11,371	9	133,065
Southern Highlands	526,398	96	8,813	2	11,054	2	546,265
Enga	283,498	96	4,014	1	7,519	3	295,031
Western Highlands	371,014	84	39,094	9	29,917	7	440,025
Simbu	242,748	93	7,201	3	9,754	4	259,703
Eastern Highlands	393,418	91	13,243	3	26,311	6	432,972
Morobe	356,100	77	46,869	10	57,743	13	460,712
Lae City	0	0	0	0	78,692	100	78,692
Madang	308,135	84	18,626	5	38,345	11	365,106
East Sepik	303,706	88	7,492	2	31,983	9	343,181
Sandaun	166,919	90	4,508	2	14,314	8	185,741
Manus	34,899	80	1,276	3	7,212	17	43,387
New Ireland	103,259	87	4,346	4	10,745	9	118,350
East New Britain	174,230	79	35,613	16	10,290	5	220,133
West New Britain	109,299	59	54,969	30	20,240	11	184,508
Bougainville	167,156	95	3,897	2	4,107	2	175,160
Papua New Guinea	4,192,561	81	311,924	6	686,301	13	5,190,786

Note: The PNG 2000 National Census records for census units have 2-digit or 3-digit codes for Province (2), District (2), Local Level Government Area (2), Local Level Government Area Ward (2) and Census Unit (3). These are combined to form a unique 11-digit geocode for every census unit in PNG.

This table was created by grouping and summing the populations for all census units for which the ward number is between 80 and 88 as *urban census units*, and all census units for which the census unit number is between 400 and 599 as *rural non-village census units*. National Capital District (Province=04) and Lae City (Province=12, District=03 and 05) were extracted separately. *Rural census units* are all the rest.

Source: NSO (2002).

Table 1.1.2 Population growth rates[a] by region, 1966–2000 (%)

Region	1966–1971	1971–1980	1980–1990	1990–2000	1966–2000
Southern	3.35	1.81	2.72	0.21	1.84
Highlands	2.07	1.95	2.05	3.65	2.49
Momase	2.35	2.30	1.82	3.36	2.48
Islands	3.59	2.40	2.90	2.30	2.69
National Capital District	–	–	4.62	2.57	3.60[b]
Papua New Guinea	2.61	2.09	2.25	3.24	2.55

[a] Growth rates are calculated as follows: $LogN(P_n) - LogN(P_0)$/intercensal period × 100. The intercensal periods used are 1966–1971, 5 years; 1971–1980, 9.1 years; 1980–1990, 9.92 years; 1990–2000, 9.92 years; 1966–2000, 33.94 years.

[b] 1980–2000 intercensal period is 19.84 years.

Sources: 1966–1990: DNPM (1999); 2000: NSO (2002).

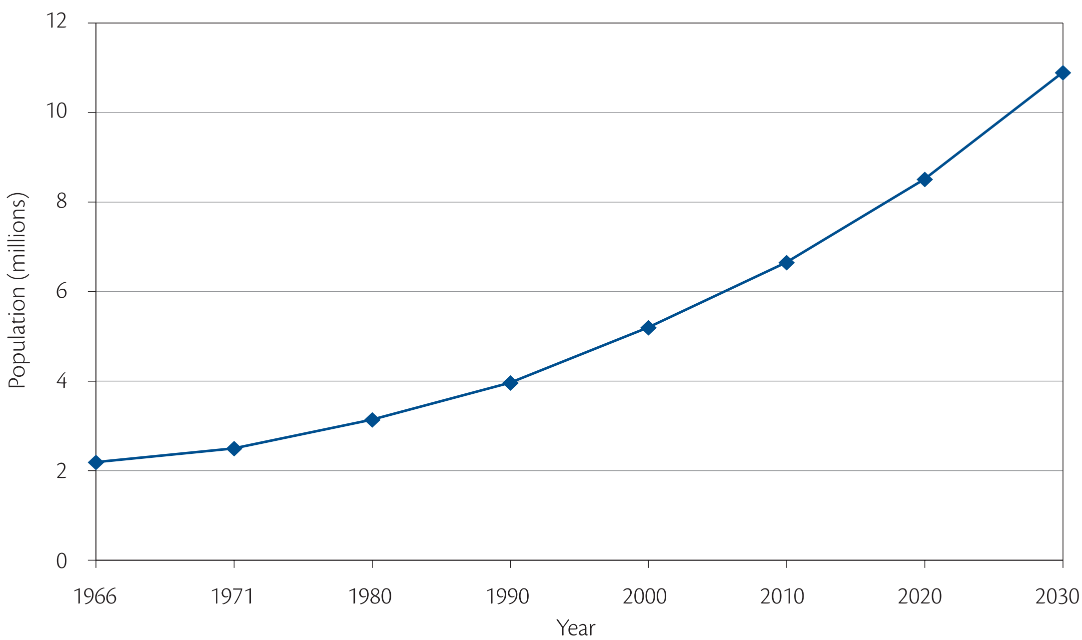

Figure 1.1.1 Population growth 1966–2000 and projected growth 2000–2030 at a constant 2.5% per year.
Sources: 1966–1990: DNPM (1999); 2000: NSO (2002).

The National Statistical Office Population Projections Task Force predicted in 1999 that the Highlands Region population will reach 3.9 million and the Momase Region population 2.9 million by around 2030.

Population distribution

The total population of PNG is not spread evenly throughout PNG. Half of the population lives in six provinces: Southern Highlands, Morobe, Western Highlands, Eastern Highlands, Madang and East Sepik. Another six provinces contain only 14% of the total population: Western, Bougainville, Oro, New Ireland, Gulf and Manus.

In 2000, 38% of the population lived in the five provinces that make up the Highlands Region, 28% lived in the Momase Region, 15% in the Southern Region, 14% in the Islands Region and 5% in the National Capital District. These proportions have remained reasonably stable over the 34-year period 1966 to 2000 (Table 1.1.3, Figure 1.1.3).

Of the total population, 686 301 (13%) are located in urban areas, notably Port Moresby (254 000), Lae (78 700), Mount Hagen (28 500), Madang (27 900), Wewak (20 250) and a number of much smaller towns and administrative centres. There are 73 urban areas, 40 of which have populations of more than 1000 people. A further 311 924 (6%) live in settlements that are classified as 'rural non-village' census units. These are boarding schools, mission stations, sawmills, logging camps and similar settlements located in rural areas, but which are not villages. The rural village population is 4 192 561 (81%).

The effect of HIV/AIDS

PNG is in the early stages of a serious epidemic of HIV/AIDS (Figure 1.1.4). The long-term influence of this epidemic on the distribution of the population is difficult to predict. The impacts on agriculture are also speculative. Most males diagnosed with HIV are aged 25–34 years old and most females are 20–34 years old.

The experience of HIV/AIDS in rural East Africa suggests that the loss of persons in the 25–45 year age group from rural communities will have a significant effect on food and cash crop production, and on the wellbeing of children. HIV/AIDS will possibly have the greatest impact in places that already have a chronic shortage of food (energy and protein), an existing labour shortage (from migration, for example), or an inability to substitute less labour-demanding crops (such as cassava) for present staple crops.

To date, by far the greatest number of infections has been diagnosed in Port Moresby. However, given the propensity of people in PNG to move between the cities and their home villages, it is also important to know the origins of persons infected because such figures may indicate which areas are at greatest risk

Table 1.1.3 Total population by region, 1966–2000

Region	1966	%	1971	%	1980	%	1990	%	2000	%
Southern[a]	422,233	19	499,273	20	588,700	19	771,193	19	787,662	15
Highlands	846,520	39	938,780	38	1,121,258	36	1,373,673	35	1,973,996	38
Momase	618,651	28	695,857	28	857,773	27	1,027,600	26	1,433,432	28
Islands	297,578	14	356,037	14	442,996	14	590,488	15	741,538	14
National Capital District	–		–		123,624	4	195,570	5	254,158	5
Papua New Guinea	2,184,982	100	2,489,947	100	3,134,351	100	3,958,524	100	5,190,786	100

[a] The total population of Southern Region in 1966 and 1971 includes the population of the present National Capital District, which was not established until Independence in 1975.

Sources: 1966–1990: DNPM (1999); 2000: NSO (2002).

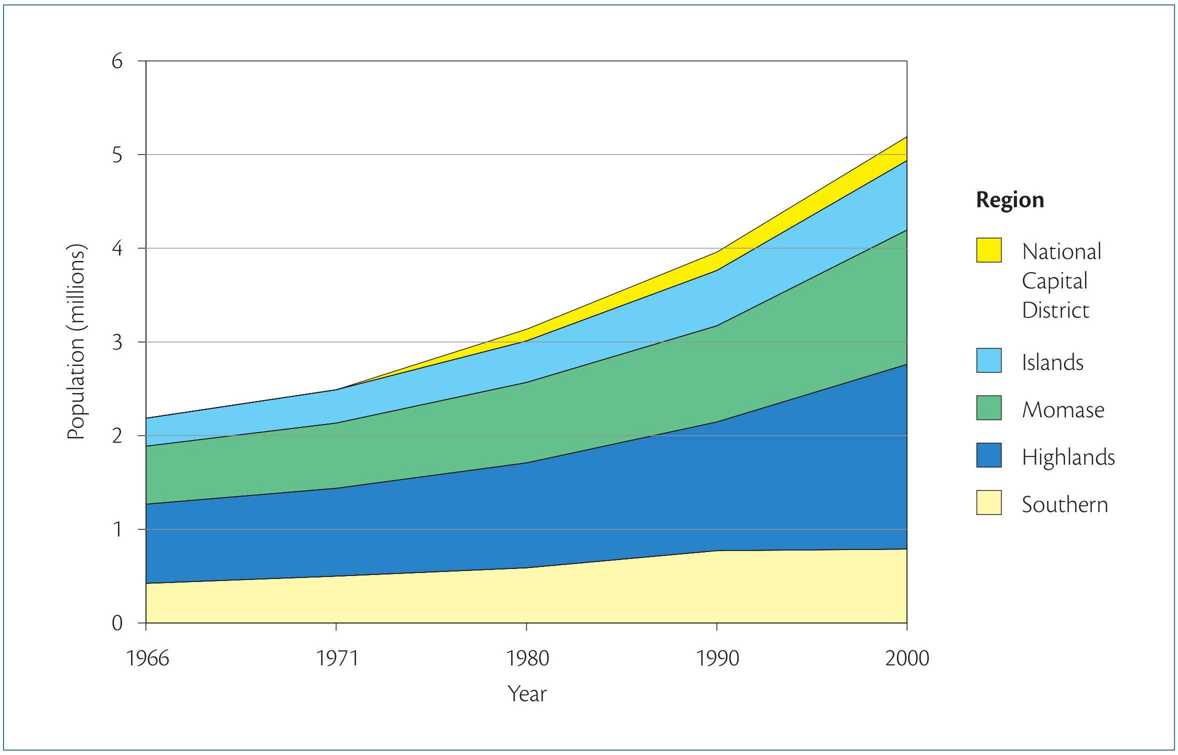

Figure 1.1.2 Population growth by region, 1966–2000. Sources: 1966–1990: DNPM (1999); 2000: NSO (2002).

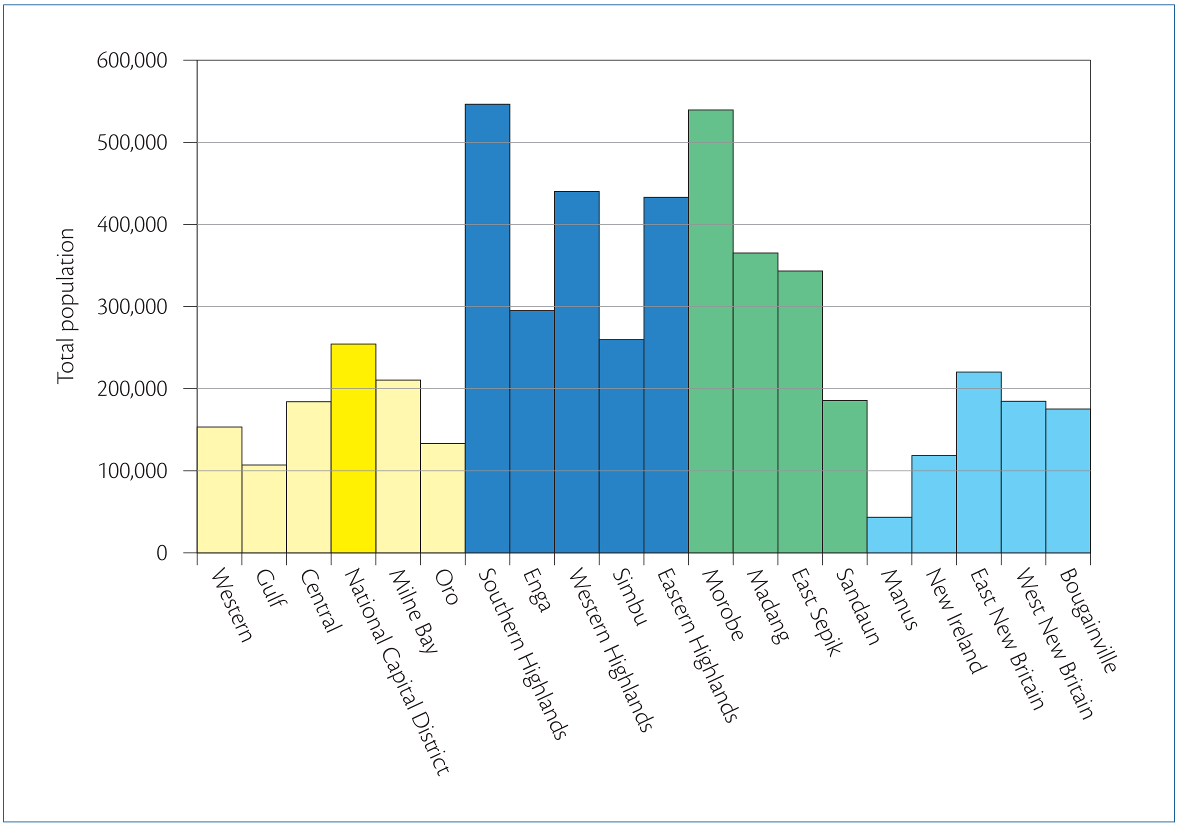

Figure 1.1.3 Total population by province, 2000. Source: NSO (2002).

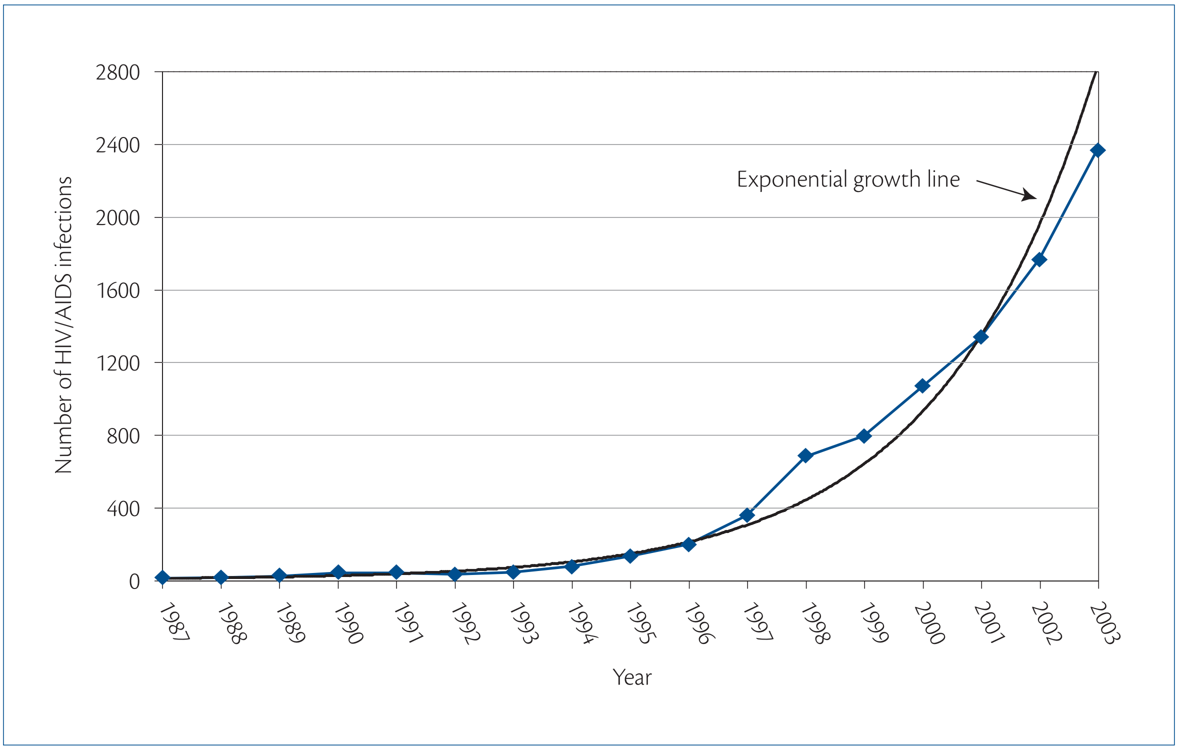

Figure 1.1.4 Number of reported HIV/AIDS infections in PNG, 1987–2003. Source: NACS (2003).

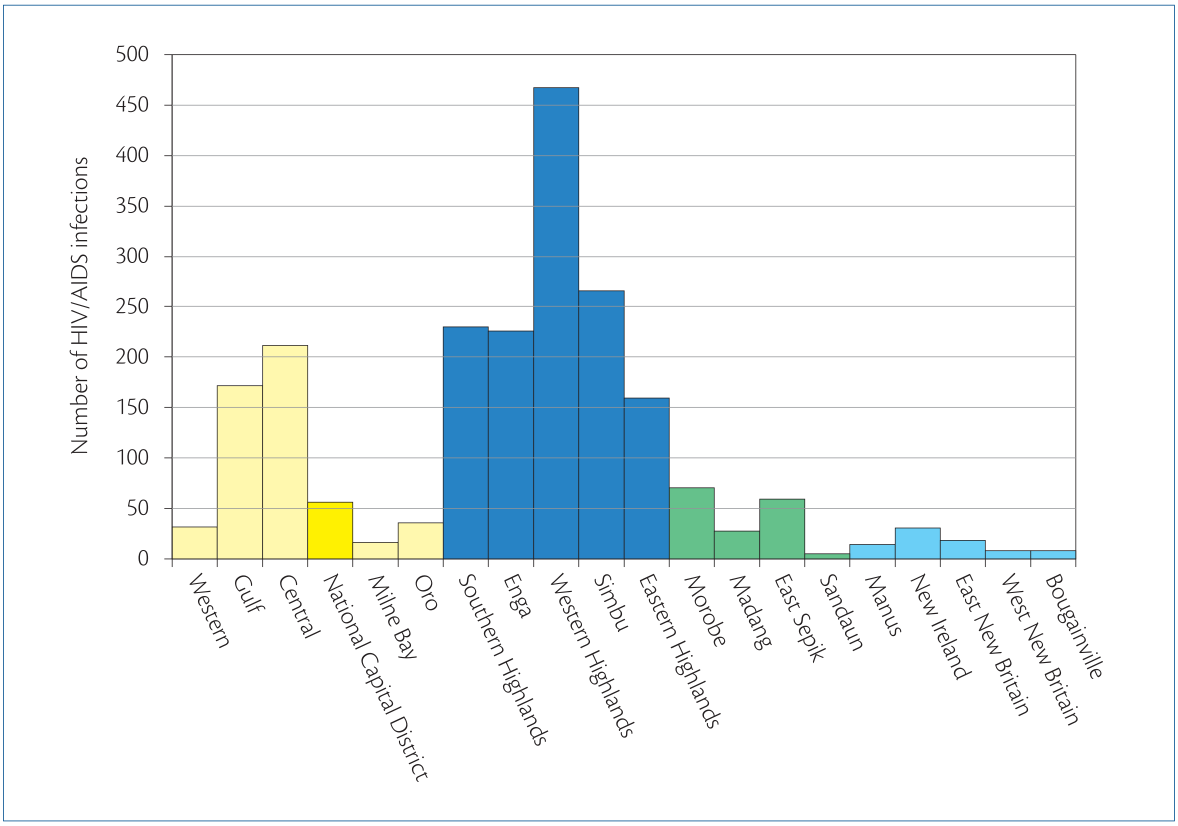

Figure 1.1.5 Number of detected HIV/AIDS infections by province of origin, 1987–2003. Source: NACS (2003).

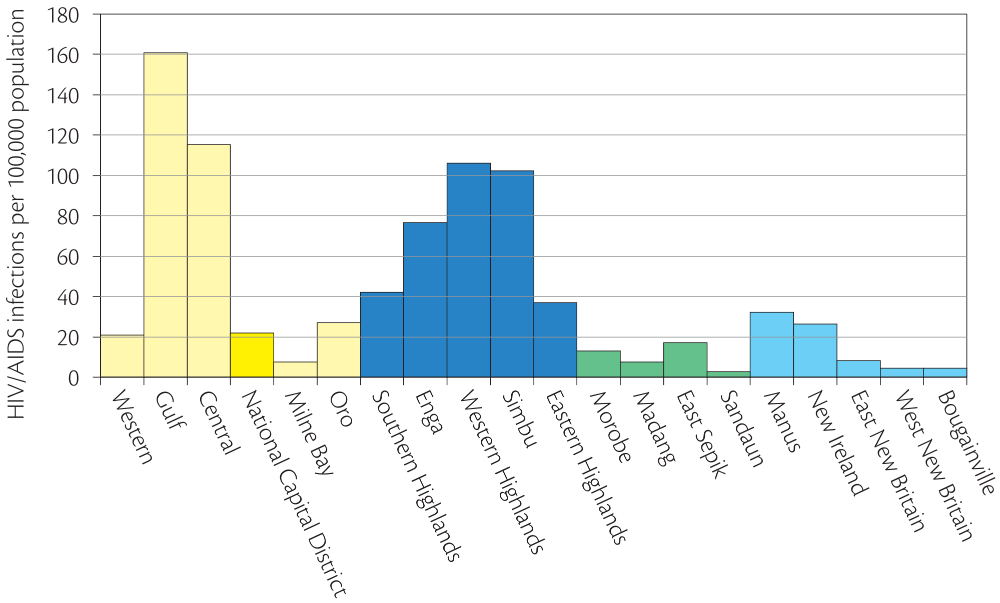

Figure 1.1.6 Rate of confirmed HIV/AIDS infections by province, 1987–2003. Source: NACS (2003).

of local epidemics. Available data, which do not represent all infections, indicate that in 2003 the largest number of infections was in people resident in Central, Gulf and the five highlands provinces (Figure 1.1.5). On the other hand, crude estimates of the number of people infected per total provincial population suggest that infection rates in people from the Southern and Highlands regions (between 55 and 58 per 100 000) are up to five times higher than infection rates in people from the Momase and Islands regions (10 to 11 per 100 000) (Figure 1.1.6). This difference is probably associated with the relative ease of access to Port Moresby, Lae and the Highlands Highway, and possibly also to the relative frequency of testing for the infection in different parts of PNG. In mid 2004 it was reported that around one in every 50 (or 2000 per 100 000) pregnant women admitted to Lae Hospital were HIV positive. Pregnant women were being tested in Lae as part of their antenatal examination. Because most pregnant women are married, and married women are not usually seen as being at 'high risk' of infection, this statistic suggests that the epidemic has moved into the general population and is not restricted to groups who practice risky personal behaviour, such as frequent promiscuous unprotected sexual activity or drug injecting.

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1.2 Land use

The total land area of PNG is 459 854 km^2. In land use studies of PNG, two different measures of 'land use intensity' have been developed. The first, used in the Papua New Guinea Resource Information System (PNGRIS), examines the proportion of the total land area that is in use at a particular time. The second, applied in the Mapping Agricultural Systems of Papua New Guinea Project (MASP), looks at how often land is used through time (see Section 1.15 for detailed descriptions of these databases).

Understanding land use intensity in PNGRIS

PNGRIS, developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Water and Land Resources, is based on the interpretation of air photographs. CSIRO approached the problem of how to measure land use intensity in shifting cultivation systems over the whole of PNG by first making a distinction between 'used land' and 'unused land' (Figure 1.2.1, Table 1.2.1).

Unused land is all land that is not classed as being used and is usually forest that has never been used for agriculture, but may include swamps. This land may be used for hunting and gathering.

Used land is divided into 'cultivated land' and 'uncultivated land'. Cultivated land includes 'land in current use', that is, land which is currently producing food or cash crops, and 'land in fallow', which is not currently producing, but which has been productive in the past and will be used again to produce food (see Section 3.8). **Everywhere else in this book we use the term 'land used for agriculture' to refer to the CSIRO class 'cultivated land'.** Much fallow land is covered in secondary forest at various stages of regrowth and appears to observers unfamiliar with shifting cultivation systems to be not in use. The inclusion of fallow land as used land is justified because fallows are an integral part of a rotational production system. Tree crops, including coffee, cocoa (and the trees used to shade them) and fruit and nut trees, form an integral part of this complex mix of productive and fallow used land, but are moved about the landscape less than food crop-producing areas.

Used land subclassed as uncultivated land in PNGRIS is land that is not part of a rotational production system, but is nevertheless irregularly interfered with by people. Thus grasslands (including subalpine, alpine and savanna grasslands) are classed as used land in PNGRIS. Grasslands are included because people burn them, and sago is included because some sago is managed and planted by people.

PNGRIS also employs the concept of 'anthropogenous' vegetation, a term first used by the American geographer Carl Sauer in the 1950s in his studies of historical changes in landscapes brought about by people.[1] The term is not clearly defined in PNGRIS but is applied to both cultivated and uncultivated

1 Sauer (1952) used the term 'anthropogenic' vegetation.

land. When applied to cultivated land it refers to the natural vegetation growing on fallow land, and is used as an alternative measure of land use intensity. When applied to uncultivated land it indicates that part or all of an area could have been interfered with by people. Anthropogenous vegetation is not applied to sago stands or alpine grassland.

Land use intensity measures are developed only for cultivated land. They are based on a subjective interpretation (that is, the measure depends on the person doing the interpretation and not on a fixed and defined measure that can be used by anyone) of patterns on air photographs of the cultivated land that has anthropogenous vegetation growing on it and the area of land that is in current use. Land use is highest where an estimated 75% of cultivated land has vegetation that is influenced by human activity and over 10% is estimated to be in current use (Figure 1.2.1, Table 1.2.1).

While this conceptual structure can be difficult to understand and can lead to misinterpretation, in practice, with careful use of the PNGRIS land use classes, it is easy to distinguish between cultivated land and all other land, and to examine patterns of land use intensity on cultivated land.

Table 1.2.1 Main land uses and land use intensity in PNGRIS

Land use	Total land area (km²)	Total land area (%)	Anthropogenous (%)	Current use (%)
Used land				
Cultivated land[a]				
Very high with tree crops	2,881	0.6	≥75	>20
Very high	1,711	0.4	≥75	10–20
High	6,237	1.4	>50	5–10
Moderate	15,291	3.3	20–50	1–5
Low	34,115	7.4	20–50	<1
Extremely low and very low	57,623	12.5	<20	<1
Total	117,858	25.6		
Uncultivated land				
Grassland	9,482	2.1	up to 100	0
Sago stands	8,189	1.8	0	0
Subalpine grassland	1,232	0.3	up to 100	0
Alpine grassland	1,033	0.2	0	0
Savanna woodland	2,529	0.5	up to 100	0
Total	22,465	4.9		
Unused land				
Forest	319,531	69.5		
Total land area	459,854	100.0		

[a] Everywhere else in this book we use the term 'land used for agriculture' to refer to the CSIRO class 'cultivated land'.

Sources: Bellamy (1986:116); PNGRIS.

An analysis of PNGRIS shows that in 1975:

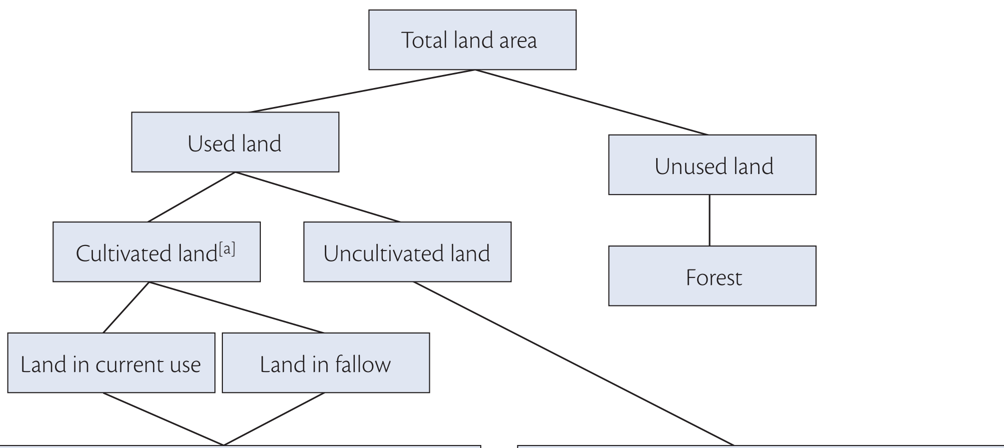
- 319 531 km^2, or about 70% of the total land area of PNG was unused (Table 1.2.1, Figure 1.2.2).
- Of the 140 323 km^2 of used land, 22 465 km^2 (5% of the total land area and 16% of used land) was uncultivated and was grassland, subalpine or alpine grassland, savanna woodland, or sago stands.
- A further 117 858 km^2 (25% of the total land area and 84% of the used land), was cultivated. This is land that is in current use *and* land under fallow. Some of the fallow land is covered in secondary forest.

The PNGRIS land use map was updated in 1996 when it was estimated that the area of 'significant land use' had expanded by about 15% between 1975 and 1996, from 60 235 km^2 to 69 183 km^2. These figures include land uses such as mining, oil palm estates and reforestation.

The greatest area of used land was in Madang Province, which accounted for nearly 14% of all used land in PNG. Morobe Province accounted for 10% of the national total (Table 1.2.2). In four provinces, the area of used land as a proportion of the total provincial area was 50% or greater: Madang (56%), Bougainville (55%), Western Highlands (50%) and Eastern Highlands (50%). Western Province had the smallest proportion of used land (8%). The very high figure for Manus Province (83%) reflects an error in the 1975 air photo interpretation of the area of anthropogenous vegetation on Manus Island.

Almost half of the cultivated land is used at extremely low and very low intensities (Figure 1.2.3, Table A1.2.1). On this land, less than 20% of the vegetation is anthropogenous and less than 1% is in current use. A further 29% of used land is used at low intensity. At the other extreme, only about 4% is used at very high intensity, where more than 75% of vegetation is anthropogenous and more than 10% of land is in current use.

The highlands provinces have the greatest proportions of cultivated land used at high intensities; more than one-third of cultivated land in both Enga and Western Highlands is used at high intensity (Figure 1.2.4). Simbu Province has a significant area (43%) of very



Code	Class	Anthropogenous (%)	Current use (%)
0	Very high with tree crops	»75	>20
1	Very high	»75	10–20
2	High	>50	5–10
3	Moderate	20–50	1–5
4	Low	20–50	<1
5	Very low	10–20	<1
6	Extremely low	<10	<1

Code	Class	Anthropogenous (%)	Current use (%)
7	Grassland	Up to 100	0
8	Sago stands significant	0	0
9	Subalpine grassland	Up to 100	0
10	Alpine grassland	0	0
11	Savanna woodland	Up to 100	0

[a] Everywhere else in this book we use the term 'land used for agriculture' to refer to the CSIRO class 'cultivated land'.

Figure 1.2.1 PNGRIS classification of land use and land use intensity. Source: PNGRIS.

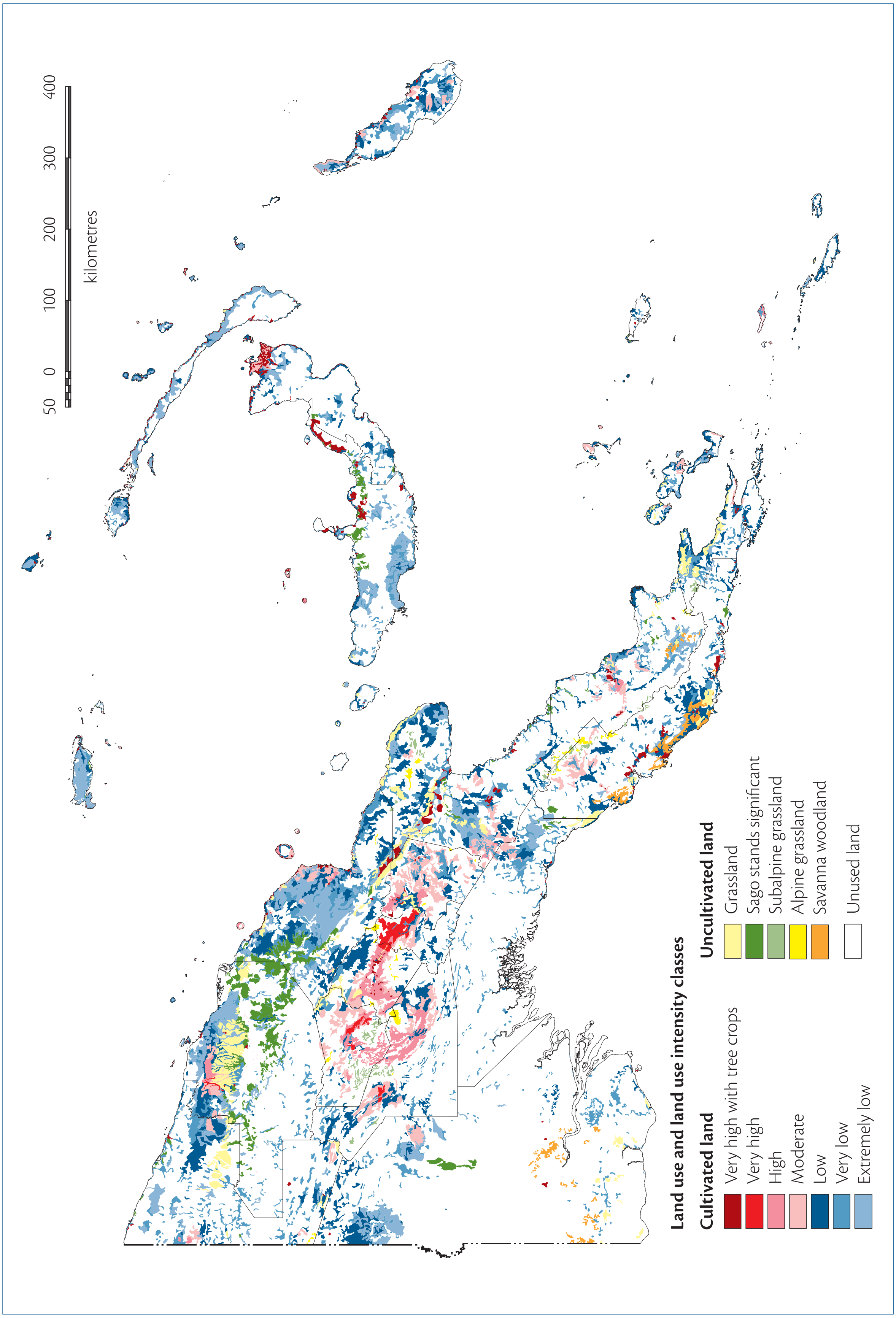


Figure 1.2.2 Land use and land use intensity from PNGRIS, 1975. Source: PNGRIS.

high intensity land use. East New Britain, a lowlands province, stands out as the only province in PNG where a significant area of land is used at very high intensity with tree crops.

The area of 'village only' land use increased by around 11% between 1975 and 1996 (Table 1.2.3). The expansion in the area of used land is much smaller proportionately than the increase in population over the same period. Rather than expanding agriculture into land not presently in use, people in PNG are using land more intensively.

Understanding land use intensity in MASP

Land use intensity in the Mapping Agricultural Systems of Papua New Guinea Project (MASP) database is based on Ruthenberg's measure, known as R, which is a measure of how often land is used. It is particularly useful when applied to shifting cultivation systems because it compares the time that land is in cultivation with the time that it is in

Table 1.2.2 Total land area and cultivated land area by province, 1996

Province	Total land area		Cultivated land area[a]		Cultivated land as a proportion of total land area (%)
	(km^2)	(%)	(km^2)	(%)	
Western	97,065	21.1	7,931	6.7	8.2
Gulf	33,847	7.4	3,801	3.2	11.2
Central	29,954	6.5	6,407	5.4	21.4
Milne Bay	14,125	3.1	5,691	4.8	40.3
Oro	22,510	4.9	4,258	3.6	18.9
Southern Highlands	25,698	5.6	7,112	6.0	27.7
Enga	11,839	2.6	3,749	3.2	31.7
Western Highlands	8,897	1.9	4,482	3.8	50.4
Simbu	6,022	1.3	2,515	2.1	41.8
Eastern Highlands	11,006	2.4	5,539	4.7	50.3
Morobe	33,525	7.3	12,245	10.4	36.5
Madang	28,732	6.2	16,046	13.6	55.8
East Sepik	43,720	9.5	8,992	7.6	20.6
Sandaun	36,010	7.8	8,211	7.0	22.8
Manus	2,098	0.5	1,747	1.5	83.3
New Ireland	9,615	2.1	4,531	3.8	47.1
East New Britain	15,109	3.3	3,772	3.2	25.0
West New Britain	20,753	4.5	5,676	4.8	27.4
Bougainville	9,329	2.0	5,153	4.4	55.2
Papua New Guinea	459,854		117,858		25.6

[a] Everywhere else in this book we use the term 'land used for agriculture' to refer to the CSIRO class 'cultivated land'.

Source: PNGRIS.

fallow. R is the ratio between the length of active cultivation to the length of the total cultivation cycle (active cultivation and fallow), in years, multiplied by 100. The highest value that R can reach is 100, which represents permanent use. In MASP, land use intensity is measured by converting classes of cultivation period and classes of fallow period into an R-value.

The agricultural systems in MASP are located only within the 117 858 km² of land classified in PNGRIS as used and cultivated, that is, 25% of the total land area of PNG (Figure 1.2.5).

If R is used as the measure of land use intensity, around 71% of the cultivated land in PNG is used at very low intensity (R-value less than 10) and a further 20% at low intensity (Figure 1.2.6, Table A1.2.2). At the other extreme, only 2% is used at high and very high intensity.

Provinces with the largest areas of land used at very low and low intensity are Western, East Sepik, Madang, Sandaun and Gulf (Figure 1.2.7). Large areas used at high and very high land use intensity occur in Enga, Southern Highlands, East New Britain, Eastern Highlands and Western Highlands provinces. Simbu Province, which has large areas of very high intensity land use when using the PNGRIS measure, does not stand out in the MASP data.

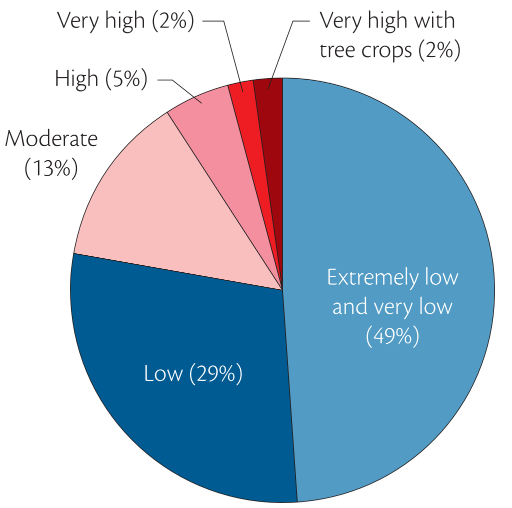


Figure 1.2.3 Proportion of cultivated land by PNGRIS land use intensity class, 1975 (km²). Source: PNGRIS.

Table 1.2.3 Change in village land use, 1975–1996

Province	Increase in village land use 1975–1996 (km²)	(%)
Western[a]	709	26
Gulf	141	16
Central	440	9
Milne Bay	134	3
Oro[b]	417	20
Southern Highlands	329	5
Enga	168	5
Western Highlands	312	7
Simbu	86	4
Eastern Highlands	49	1
Morobe	667	11
Madang	508	8
East Sepik	304	11
Sandaun	531	18
Manus[c]	463	228
New Ireland	121	8
East New Britain	451	21
West New Britain[b]	594	64
Bougainville	n.a.	n.a.
Papua New Guinea	6424	11

[a] Refugee resettlement areas and Ok Tedi mine.
[b] Oil palm land settlement schemes occur in these provinces.
[c] Manus figures are an error caused by a misinterpretation of the area of anthropogenous vegetation in 1975.
n.a. = not available
Source: McAlpine et al. (2001:279).

About 2.9 million people, or 70% of the total rural population, live in areas of very low or low land use intensity. Just over 12% of the rural population (513 000 people) live in areas of high or very high land use intensity (Table A1.2.3). Provinces with the largest numbers of people living in areas of high or very high land use intensity are Enga (with over 190 000 people living in very high land use intensity areas), Southern Highlands, East New Britain, Eastern Highlands and Western Highlands (Figure 1.2.8).

Land use intensity measures in PNGRIS and MASP compared

The two land use intensity measures might be expected to produce similar results. However, they have been created using different methods and they measure different things.

Land use intensity in PNGRIS is measured as the proportion of the *total* land area under different uses in the 1970s. It is derived from an interpretation of air photographs of the environmental outcomes of cultivation. The quality of an environment will influence the outcome, because better environments will recover faster from cultivation than poorer environments.

Land use intensity in MASP, on the other hand, is based on estimates of the time that land is under cultivation compared to the time it is in fallow. These estimates are based on interviews with villagers and field observations of land use practices throughout PNG between 1990 and 1995.

Rather than making a direct comparison of the two measures, a more useful analysis is to examine the PNGRIS measure of land use intensity (derived from vegetation analysis) against the MASP R-values (derived from a measure of how often land is used) in order to see where similar R-values result in different vegetation patterns, and then to see if these differences can be explained.

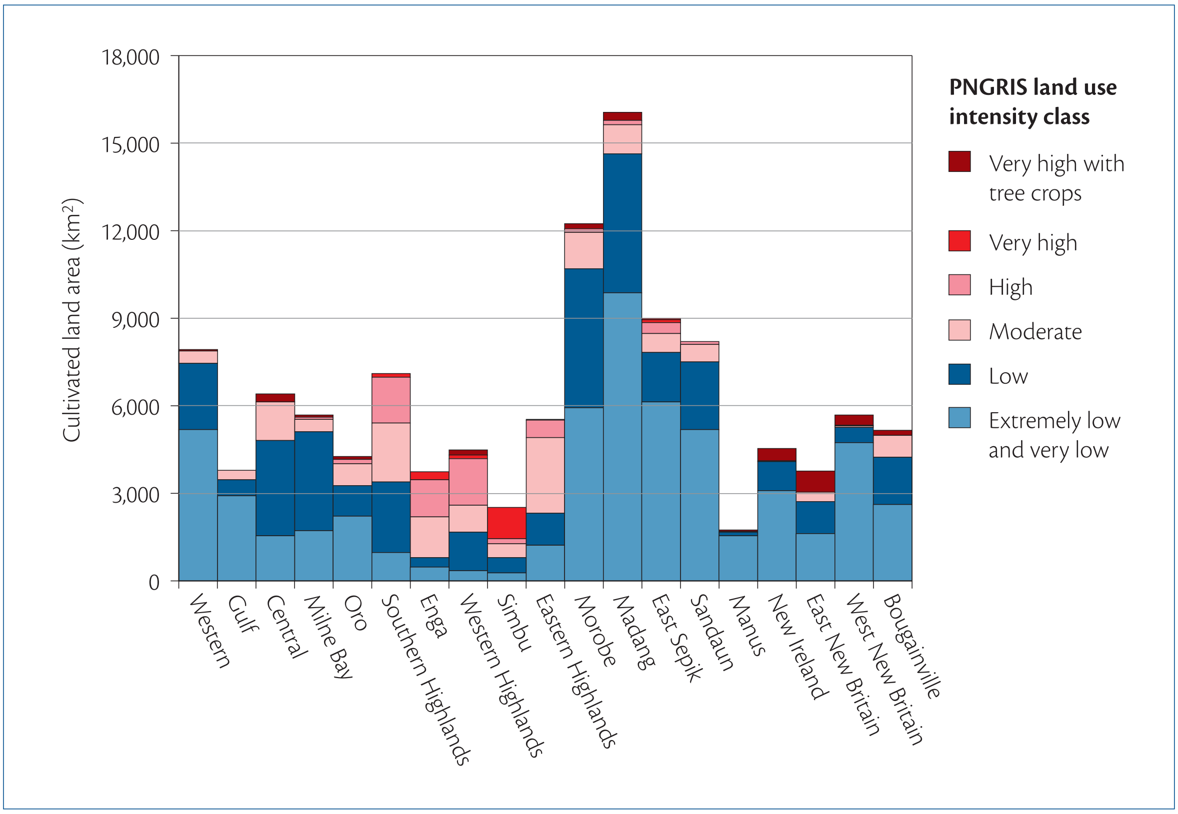


Figure 1.2.4 Cultivated land area by PNGRIS land use intensity class and province, 1975. Source: PNGRIS.

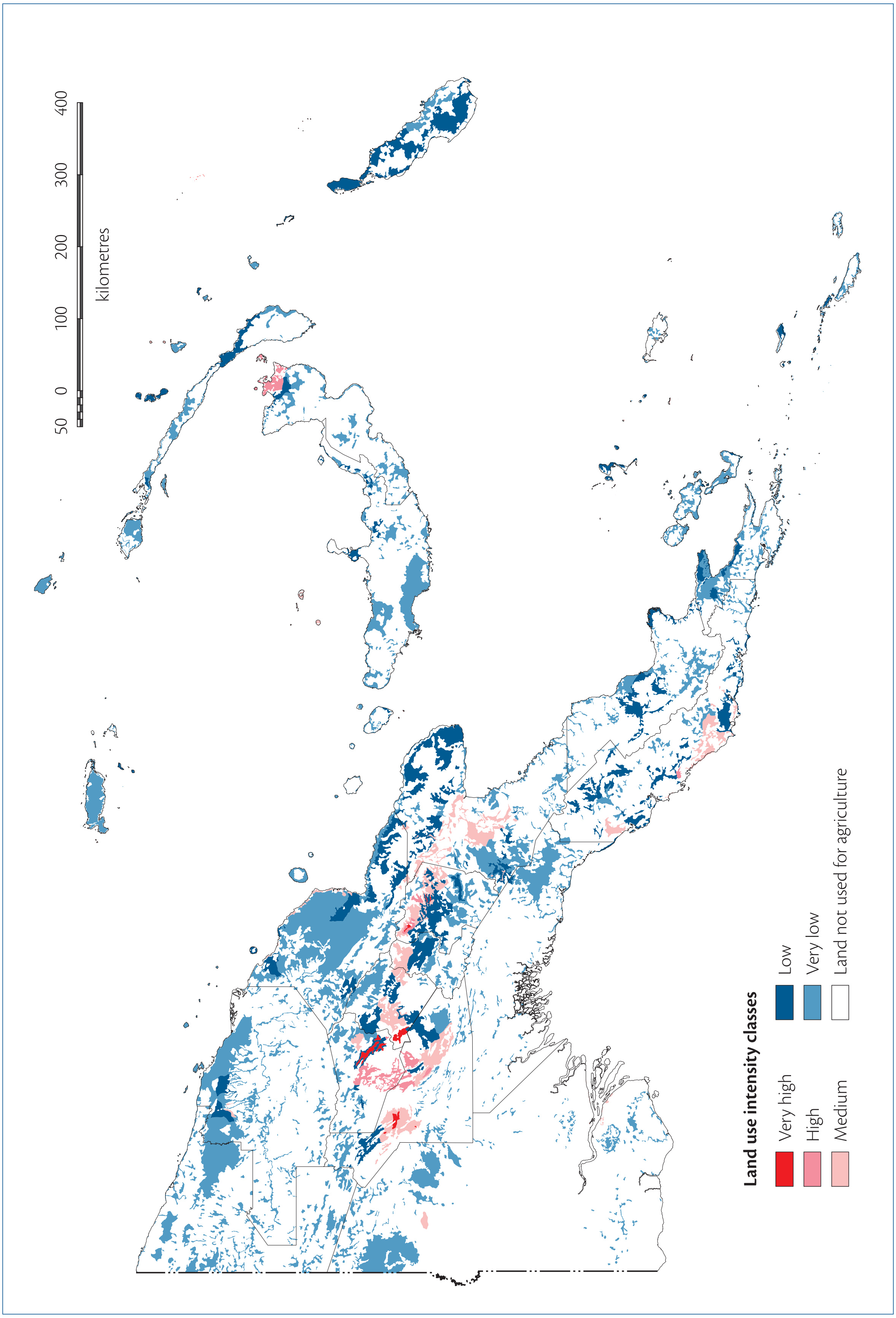


Figure 1.2.5 Land use intensity (R-value) from MASP, 1995. Source: MASP.

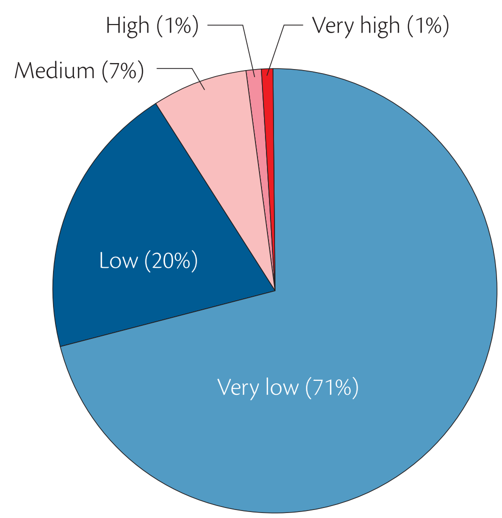


Figure 1.2.6 Proportion of cultivated land by MASP land use intensity class (R-value), 1995 (km²). Source: MASP.

Land use intensity and population density

Logically, a positive association should be expected between population density and land use intensity. Population density is, on average, higher where land use intensity is higher (Figures 1.2.9, 1.2.10, Table A1.2.4), but a lot of variation occurs. Reasons for the high levels of variation between population density and land use intensity may relate to the mapping units used; in this case agricultural systems, which were defined on attributes not associated with population density or land use intensity. It may also relate to a slowness, or an inability, in some systems, of people to respond to increases in population by intensifying their agricultural systems. The R-value is a measure of land use intensity on land used for food production only, and the ability to earn cash incomes from the land may be another reason why there is not a better match between population density and land use intensity, when R-value is used as a measure of land use intensity.

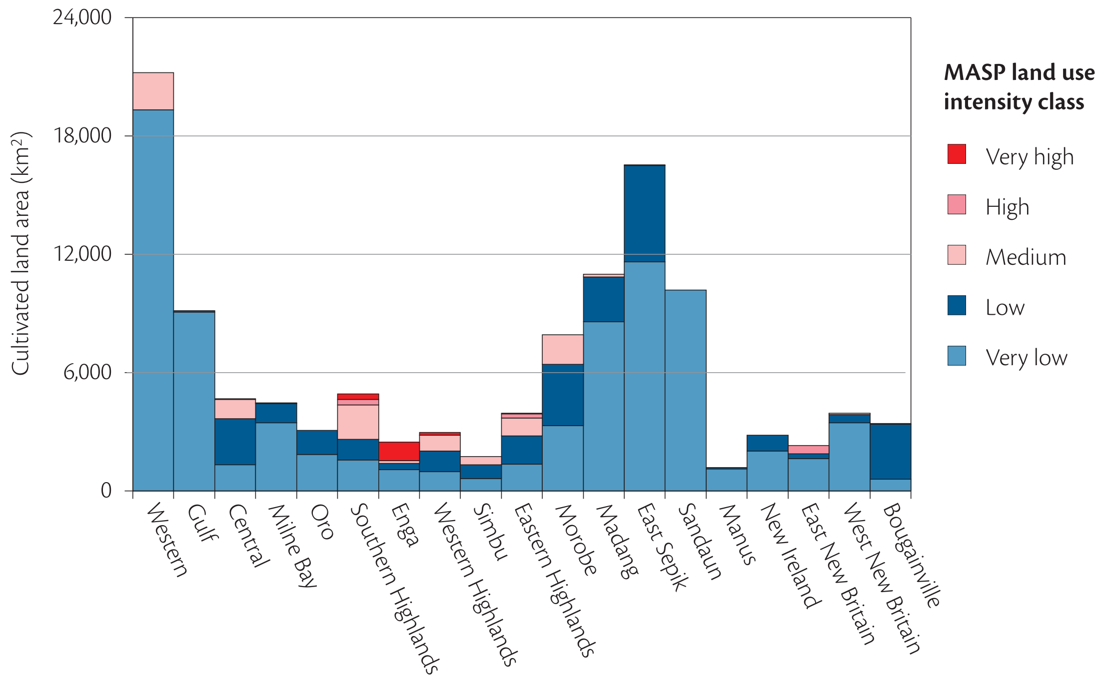


Figure 1.2.7 Cultivated land area by MASP land use intensity class (R-value) and province, 1995. Source: MASP.

FAO statistics on land use in PNG

Significant differences exist between statistics presented by the Food and Agriculture Organization of the United Nations (FAO) on land use in PNG and those that can be derived from PNGRIS. The FAO statistics require comment because they are easily available from the FAO website and because they are frequently quoted in PNG Government documents and consultants' reports.

In 1999, the FAO figures estimated 'agricultural land' in PNG to be 760 km^2 and 'arable land' as 60 km^2, compared with the PNGRIS estimate of 117 858 km^2 'cultivated land'. This is a difference of several orders of magnitude.

Some of the difference arises because the FAO figures refer to 'agricultural land' and the PNGRIS figures refer to 'cultivated land'. FAO defines 'agricultural land' as the sum of the areas of 'arable land', 'permanent crops' and 'permanent pasture'. 'Arable land' is defined by the FAO as 'land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily under fallow (less than five years)'. The FAO category of 'agricultural land' excludes the large amount of land in PNG that is under fallow for periods of more than five years. In contrast, the PNGRIS class of 'cultivated land' includes all land in fallow.

If the PNG population is brought into the analysis, serious problems that go beyond definitions are revealed in the FAO figures. For example, if around 0.08 hectares of land is cultivated for food production for every person in PNG (a reasonable estimate), and with a rural village population of 4.2 million in 2000, it follows that there had to have been at least 336 000 ha, or 3360 km^2, of 'arable land' in PNG in 2000,[2] not 60 km^2, or even 760 km^2.

2 4.2 million people × 0.08 ha = 336 000 ha or 3360 km^2 (there are 100 ha in 1 km^2).

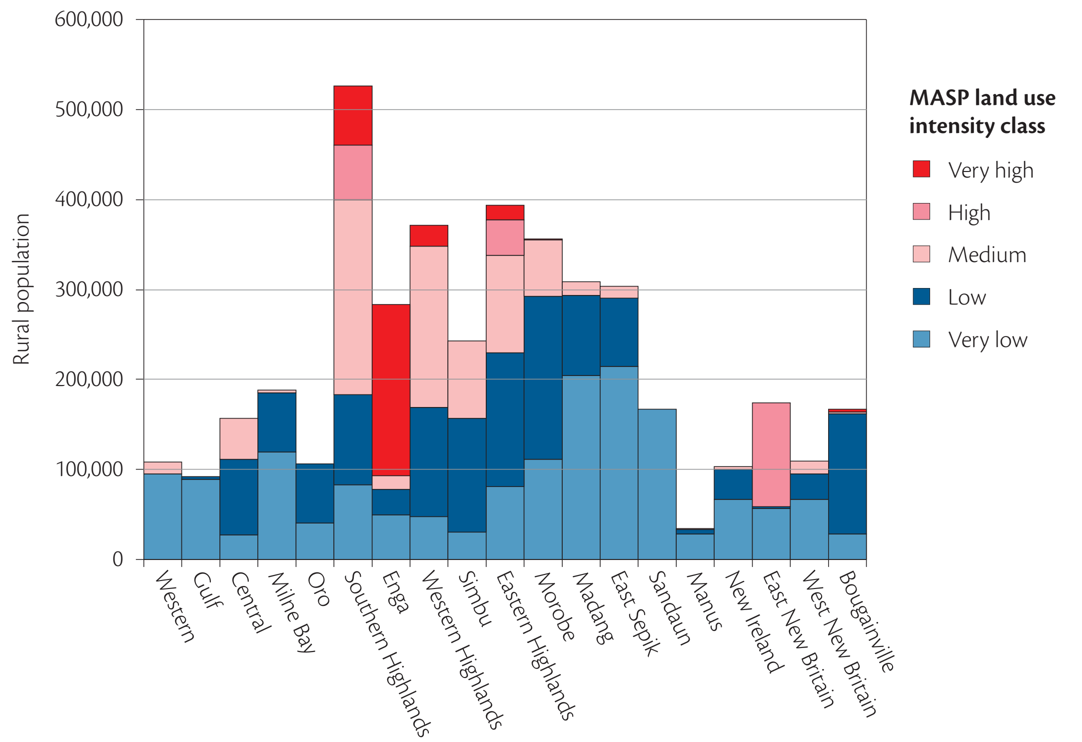


Figure 1.2.8 Number of rural people living on cultivated land by MASP land use intensity class (R-value) and province. Sources: NSO (2002); MASP.

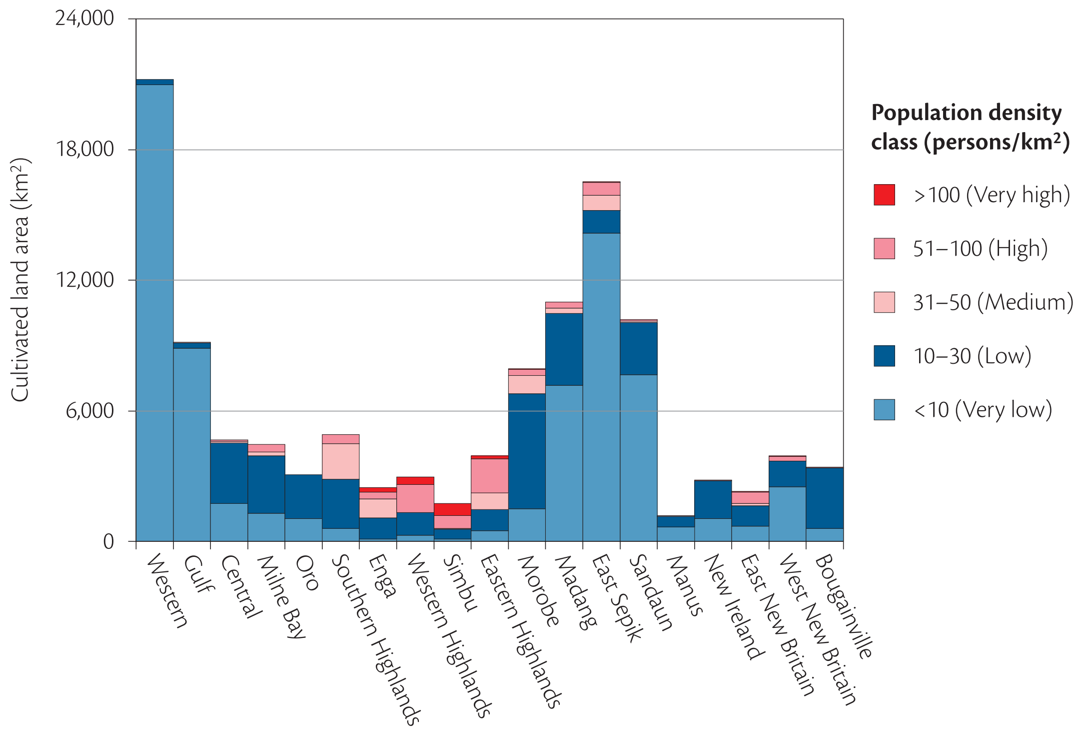


Figure 1.2.9 Cultivated land area by population density class and province, 1995. Sources: NSO (2002); MASP.

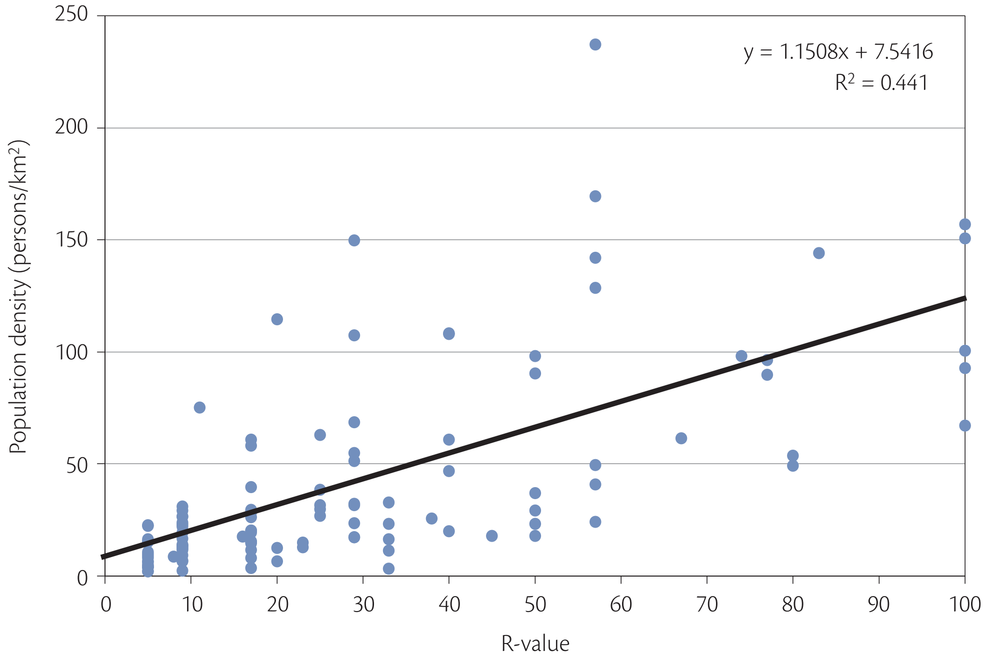


Figure 1.2.10 Association between MASP land use intensity (R-value) and population density, 1995. Sources: NSO (2002); MASP.

Furthermore, if the area of 'agricultural land' in PNG was only 760 km², as the FAO figures state, and the rural village population was 4.2 million in 2000, then the average population density on 'agricultural land' in all PNG would have been around 5526 persons per square kilometre.[3] This population density is not reached anywhere in PNG, nor in many rural places in the world.

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[3] 4.2 million people ÷ 760 km² = 5526 persons/km².

1.3 Population density

Population density is a measure of the numbers of people living within a defined area of land and is usually expressed as 'persons per square kilometre' (persons/km^2).[1]

Population density is an average figure. A population density of one person per km^2 does not mean that each person lives at least 1000 metres away from every other person. Rather, it may mean for example, that 100 people live close together in a small village, but occupy a defined area of land that measures 100 km^2.

It is important to know what land area is involved for each population density calculation. For example, the total land area of PNG is 459 854 km^2, and if there were 5.2 million people in PNG in the year 2000, the population density on the *total land area* of PNG would be 11 persons/km^2. But if the area of land used for agriculture in PNG was 117 858 km^2, then the population density on *land used for agriculture* would be 44 persons/km^2.

This section presents a general overview of population density. The associations between population density and factors such as land use intensity, altitude, or land quality are presented in other sections. The figures presented in this section are population densities within PNG agricultural systems (see Part 3) on *land used for agriculture* only.

1 A square kilometre (km^2) is a square 1000 metres long by 1000 metres wide. There are 100 hectares in one square kilometre.

Distribution of population density

The most striking thing about population density in PNG is that around 66% of the total land area is *not* occupied by people (Figure 1.3.1, Table A1.3.1), although some of this unoccupied land is used for hunting and collecting wild foods. A further 30% of the total land area is occupied at low population densities of less than 31 persons/km^2. Only 4% of the total land area is occupied at densities greater than 30 persons/km^2. The highest population densities in PNG occur in the highlands; in the Maprik area of the East Sepik; on the Gazelle Peninsula in East New Britain; and on many small offshore islands in a number of provinces. However, areas of high population density and very low population density commonly occur within the same province.

The provinces with the largest areas of land occupied at very low densities (<10 persons/km^2) are Western, East Sepik, Gulf, Sandaun and Madang.

The most densely occupied province is Simbu, where 13% of the total land area is occupied at over 100 persons/km^2 and a further 13% is occupied at densities of 51–100 persons/km^2. Other provinces with relatively large areas of land occupied at densities of more than 50 persons/km^2 are Eastern Highlands and Western Highlands. Lowlands provinces with significant areas of high population density are East Sepik, East New Britain and Milne Bay.

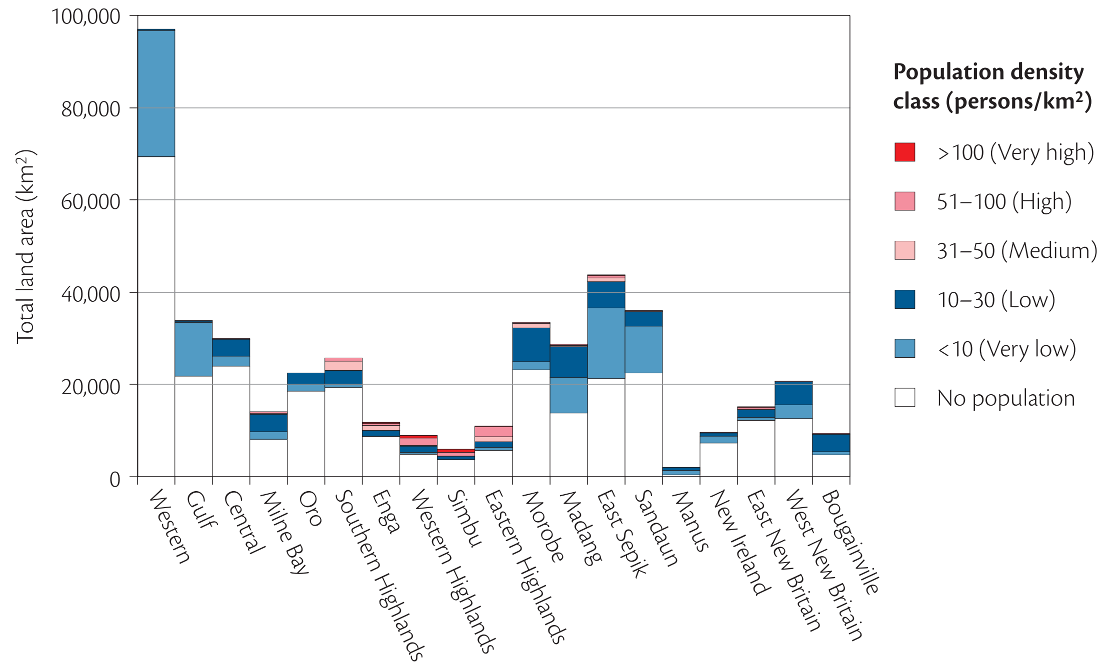

Figure 1.3.1 Total land area by population density class and province. Sources: McAlpine and Quigley (c. 1995); NSO (2002); MASP.

Importantly, however, the highest population densities in PNG occur on small offshore islands in Milne Bay, Morobe, Manus, Bougainville and other provinces (Table 1.3.1). Because they are small and isolated, these very high population density places are often overlooked. The highest population density in PNG is in the Carteret Islands north-east of Buka Island in Bougainville Province. In mid 2000, the resident population density was more than 1200 persons/km², and it has increased since then.

Population distribution and population density

Around 12% (480 000 people) of PNG's rural population live at high and very high population densities (>50 persons/km²) (Table A1.3.2). The largest numbers of people living at these densities are in Enga Province (190 000 people; 67% of the provincial population), East New Britain Province (66%), Southern Highlands Province (24%) and Eastern Highlands Province (14%). Another 766 000 people (18% of the total rural population) live at medium densities (31–50 persons/km²).

It needs to be remembered, however, that most people in PNG (2.9 million people or 70% of the population) live in areas where population densities are less than 31 persons/km². In three provinces – Gulf, Oro and Sandaun – the entire populations live at low and very low densities (Figure 1.3.2). In six other provinces – Milne Bay, Manus, Bougainville, New Ireland, East Sepik and Madang – more than 90% of the populations live at densities of less than 31 persons/km².

Table 1.3.1 Resident population in 2000, total area and population density of selected islands

Island	Population	Area[a] (km^2)	Population density (persons/km^2)
Milne Bay Province			
Iwa Island	766	3.0	255
Koyagaugau/Ole islands[b]	187	1.4	133
Kwaraiwa Island[b]	358	1.9	190
Naluwaluwali Island[b]	282	2.8	100
Wari Island[b]	707	2.2	321
Morobe Province			
Malai Island	503	1.0	503
Tuam Island	333	1.0	333
Manus Province			
M'Buke Islands	406	3.0	135
West New Britain Province			
Garove Island	3,617	52.0	70
Mundua Islands	1,315	8.0	164
Unea (Bali) Island	8,802	33.0	267
Bougainville Province			
Bougainville Island[c]	130,371	8688.0	15
Buka Island	33,809	586.0	58
Carteret Islands	979	0.8	1224
Matsungan Island	497	0.8	621
Mortlock Islands	443	1.1	403
Nissan Island	4,824	30.1	160
Nuguria Islands	502	6.1	82
Petats Island	1,145	1.9	603
Pinipel Island	901	8.6	105
Pororan/Hetau islands[d]	1,225	2.0	613
Tasman Islands	464	3.1	150

[a] The areas given are the *total* land areas. This includes land that has been used for agriculture and land that is unsuitable for agriculture because it is swampy or too steep or too high.

[b] Part or all of these populations have access to garden land on nearby (mostly very small) islands. The populations for Koyagaugau and Ole islands have been combined, as many Ole people have gardens on Koyagaugau.

[c] The population and area figures for Bougainville Island include a number of small islands near the main island where villagers cultivate land on the mainland.

[d] The figures for Pororan and Hetau islands have been combined, as Hetau people have no garden land on their island and make some gardens on Pororan Island.

Sources: Milne Bay Province: Foale (2005); Bougainville Province: Bourke and Betitis (2003); other provinces: compiled by the author.

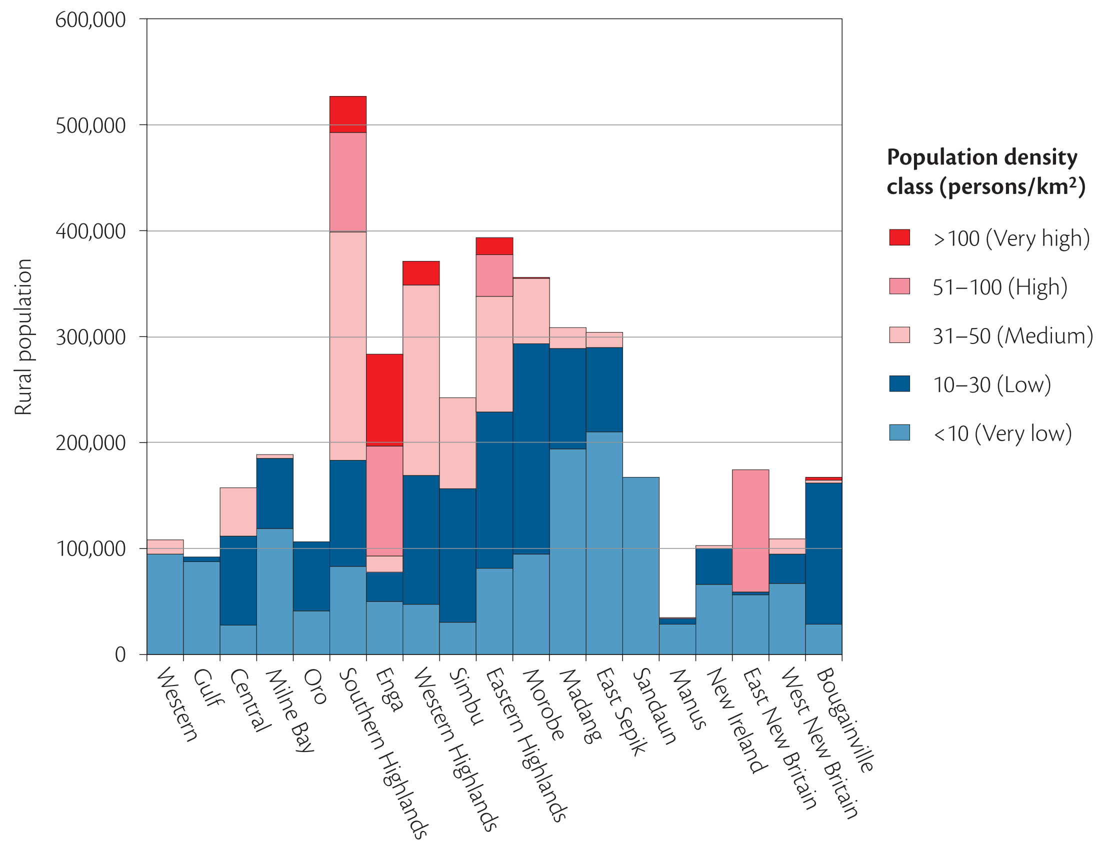

Figure 1.3.2 Rural population by population density class and province. Sources: NSO (2002); MASP.

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1.4 Internal migration

Significant numbers of people are moving temporarily and permanently within PNG.

From around 1890 until World War II, colonial governments administered indentured labour schemes that brought men from undeveloped areas with surplus labour to plantations and mines that required labour. At the end of a contract indentured labourers were returned to their homes.

During World War II, large numbers of young men were recruited as carriers and labourers by both Japanese and Allied forces. After 1946, the Highland Labour Scheme brought young men from the highlands to work in coastal locations for two years at a time. In the 1970s, the government sponsored the movement of selected rural families from mainly East Sepik, East New Britain and Simbu provinces to the north coast of West New Britain Province to produce oil palm on land settlement schemes (see Sections 5.7 and 6.7). Attempts to establish land settlement schemes based on rubber production at Gavien in East Sepik Province and Cape Rodney in Central Province have not resulted in long-term rubber production, although the settlers have remained (see Section 5.11).

Migration today is overwhelmingly informal. Young men still move more than young women, but increasingly whole families are moving.

A measure of internal migration is 'net migration', which is the difference between the movements into a province and the movements out of it. In 1980, this measure showed that people were moving out of Gulf, Simbu, Manus, Central, Southern Highlands, East Sepik, Enga and Milne Bay provinces, and were moving into West New Britain, Bougainville and Western Highlands provinces (Figure 1.4.1). The patterns of movement established in 1980 were largely maintained into 1990 and 2000 (Figures 1.4.2, 1.4.3).

The most outstanding differences between 1980, 1990 and 2000 are the movement of people out of Bougainville as a result of the civil war (1989–1997); into Western Province between 1980 and 1990 after the opening of the Ok Tedi mine; and out of East New Britain between 1990 and 2000 following the 1994 volcanic eruptions (Table 1.4.1). The proportion of families resident in National Capital District, but born elsewhere, increased considerably between 1990 and 2000.

These movements are associated with the ability to earn cash incomes in particular provinces, with most migrants moving from provinces where incomes are lowest, to provinces where incomes are highest (Figure 1.4.4).

These broad patterns at the province level were confirmed by a finer-scale study of increases and decreases in Census Division populations between the 1980 and 1990 censuses (excluding Bougainville) (Keig 2001). Keig's study revealed that four main types of internal migration are occurring within PNG:

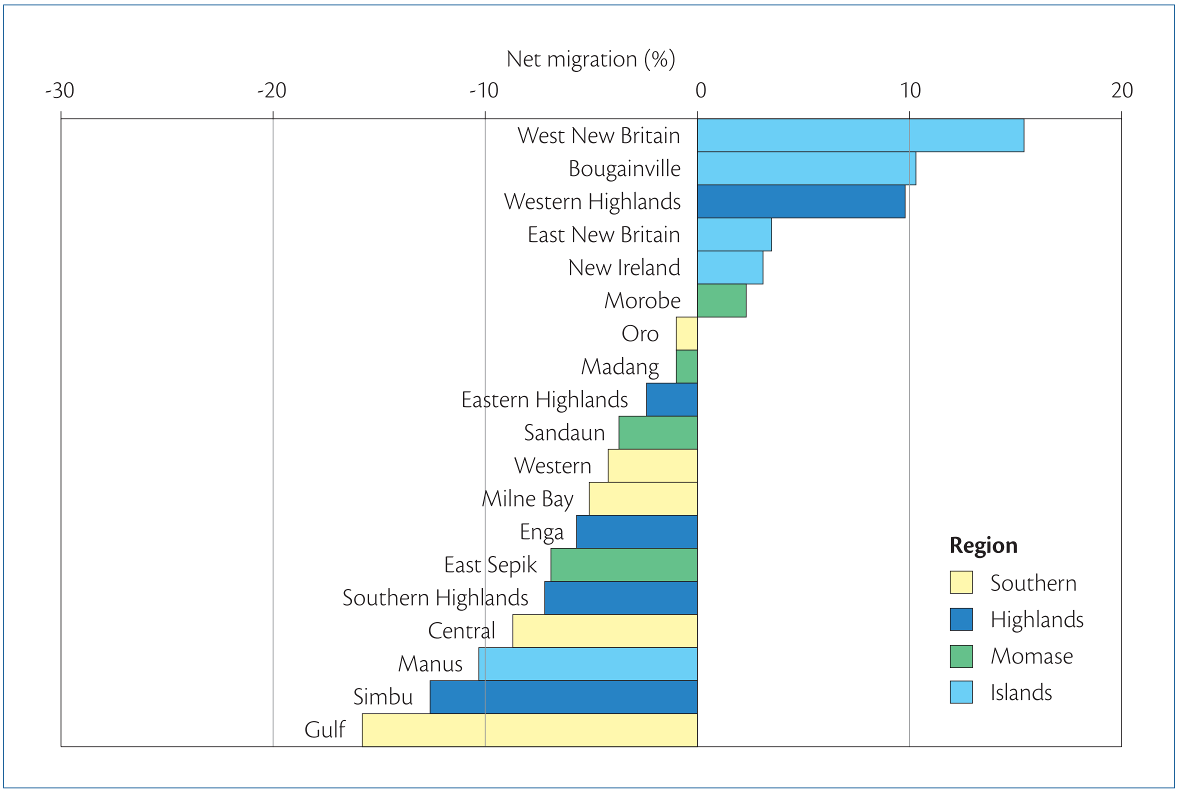

Figure 1.4.1 Net migration by province, 1980. Source: Goodman et al. (1985).

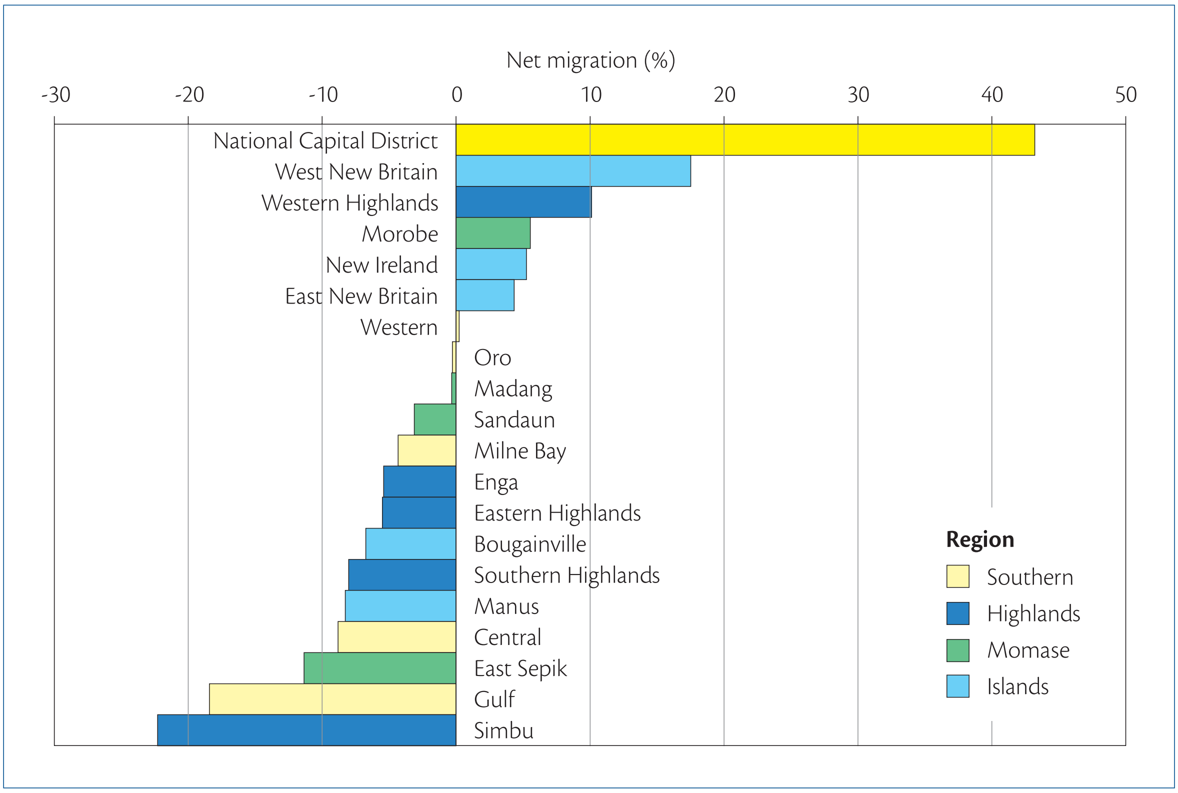

Figure 1.4.2 Net migration by province, 1990. Source: DNPM (1999).

- **Rural-to-urban** – from rural areas to the largest cities of Port Moresby, Lae, Madang, Mount Hagen and Goroka. Large informal 'settlements' have developed within these cities.
- **Rural-to-periurban** – from rural areas to the areas surrounding, but not within, main centres, such as Port Moresby, Lae, Goroka, Mount Hagen and Kokopo. Significant growth has also occurred in areas close to the smaller towns of Kimbe, Bulolo, Popondetta, Kavieng, Alotau, Mendi, Tari and Kainantu. Periurban 'settlements' are occupied at a lower density than urban settlements and a considerable amount of subsistence food is produced from them.
- **Rural-to-rural** – from rural areas in Simbu, East Sepik, Southern Highlands, Eastern Highlands, Enga, Gulf, Central and Bougainville provinces to rural areas in West New Britain, Western Highlands, Morobe, East New Britain and New Ireland provinces. Significant growth has occurred on a number of small offshore islands, such as Losuia and Misima in Milne Bay Province and the Feni Islands in New Ireland Province. However, this growth is primarily a result of natural population increase (see Section 1.1), rather than net in-migration. Complex informal extra-legal tenurial arrangements are thought to exist between landowners and migrants. These range from sharefarming, to labour in exchange for rent, to cash for rent, to the purchase of land.

Significant internal migration is also occurring within provinces. Generally people move from locations with poor environments and poor road access to those more favourable for agricultural production or close to a road. These movements are poorly documented as they are not recorded in national census data.

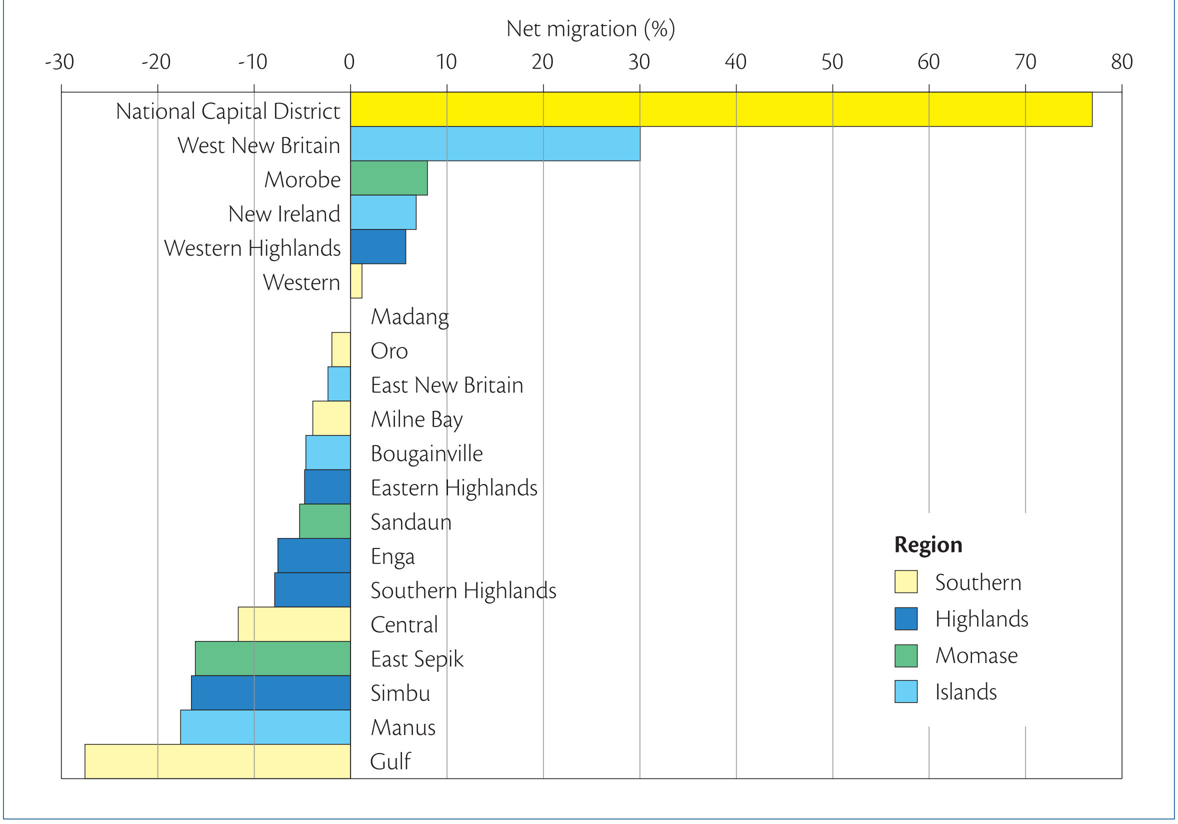

Figure 1.4.3 Net household migration by province, 2000. **Note:** This figure differs from Figures 1.4.1 and 1.4.2 in that it is based on the place of birth and the residence of household heads at the 2000 census, and not of individuals. The proportions are of the total number of households, not the total population.
Source: Calculated by the author from the PNG 2000 National Census household tables.

Table 1.4.1 Net inter-provincial migration (%)

Province	1980	1990	2000	Province	1980	1990	2000
Western	−4.2	0.23	1.18	Eastern Highlands	−2.4	−5.50	−4.78
Gulf	−15.8	−18.42	−27.56	Morobe	2.3	5.55	7.97
Central	−8.7	−8.82	−11.66	Madang	−1.0	−0.33	0.03
National Capital District	n.a.	43.20	76.91	East Sepik	−6.9	−11.36	−16.10
Milne Bay	−5.1	−4.33	−3.92	Sandaun	−3.7	−3.13	−5.30
Oro	−1.0	−0.28	−1.94	Manus	−10.3	−8.27	−17.64
Southern Highlands	−7.2	−8.01	−7.88	New Ireland	3.1	5.24	6.81
Enga	−5.7	−5.42	−7.54	East New Britain	3.5	4.34	−2.35
Western Highlands	9.8	10.11	5.73	West New Britain	15.4	17.53	30.06
Simbu	−12.6	−22.29	−16.52	Bougainville	10.3	−6.74	−4.65

Note: Net inter-provincial migration is the difference between the number of people who were born in a province and were resident in another province at the time of the census, and the number who were resident in a province at the census, but were born in another province, as a proportion of the total provincial population. The 2000 data are based on household heads, not on the total population.

Sources: 1980: calculated by Christine McMurray and published in Goodman et al. (1985:79); 1990: DNPM (1999); 2000: calculated by the author from the PNG 2000 National Census household tables.

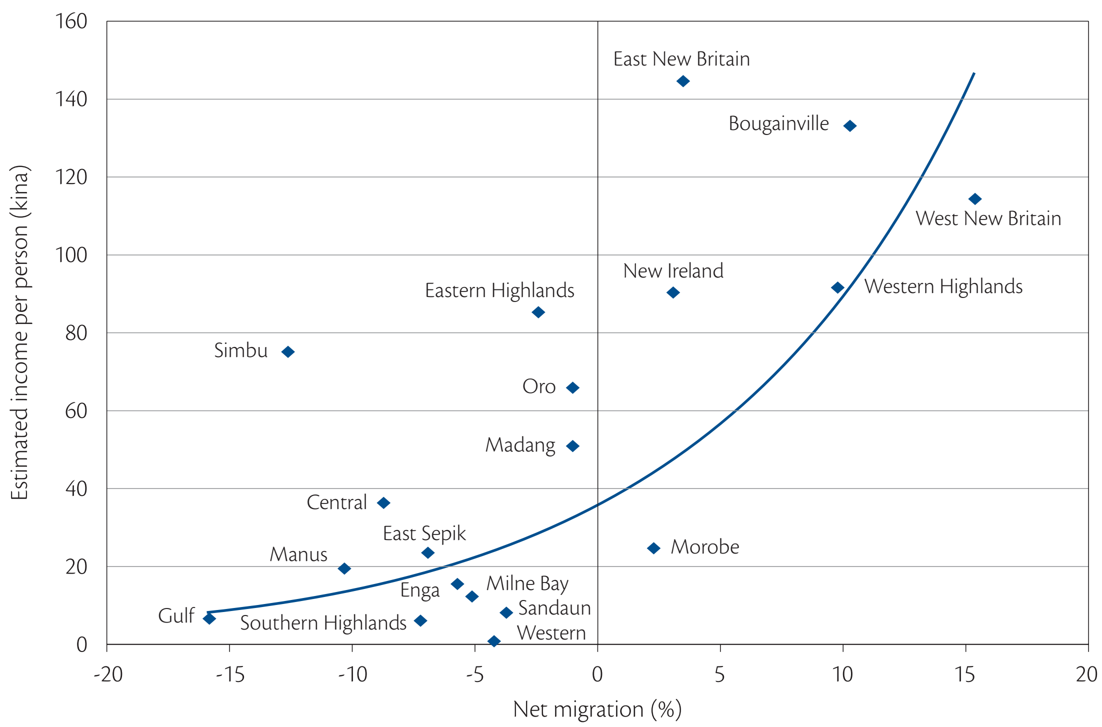

Figure 1.4.4 Association between net migration, 1980, and estimated cash income per person, 1985.
Source: Goodman et al. (1985).

In some locations people move temporarily to lower or higher altitudes for some weeks every year to make sago or to harvest pandanus nuts, sources of food which do not grow at the altitude of their settlements (see Section 1.13).

- **Rural-to-resource projects** – from rural areas to the vicinity of major mining and oil projects, such as to the Porgera gold mine (Enga Province) and to the Ok Tedi copper mine (Western Province).

Destination areas are in general around, as well as in, major towns or large mining projects; around successful land settlement schemes (see Section 6.7); on good quality land (see Section 1.12); and in places with good access to roads, markets and services (see Section 1.14).

Source areas are mainly locations with poor access to services, low quality land, few employment opportunities, or 'troubled' areas (areas with customary land tenure issues, sorcery, or criminal activity, for example). It is possible that difficult access resulted in a poor census in 1990 that has exaggerated the loss of people from such areas. Nevertheless, the trends are very clear.

It can be concluded that in many parts of PNG people are moving from areas they perceive as disadvantaged to areas they perceive as advantaged. That is, from poor quality land with poor access to markets and services, to higher quality land with better access to markets and services and with increased chances to engage in the cash economy.

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1.5 Rainfall

Rainfall is a direct influence on plant growth and must be taken into account in any discussion of agriculture. PNG is one of the wettest countries on earth; much of PNG regularly receives 2000–4000 mm of rain per year, and a few areas of the country receive more than 7000 mm of rain every year. Conversely, in other places annual rainfall is below 1500 mm (for example, Port Moresby). In some places there is no discernible seasonal pattern to rainfall, while in others rainfall is strongly seasonal. These rainfall patterns are the most important determinant of soil water availability.

Annual rainfall

Two digital maps of annual rainfall exist for PNG. The first is derived from PNGRIS in which the annual rainfall for each resource mapping unit (RMU) is mapped (Figure 1.5.1). (See Section 1.15 for an explanation of PNGRIS and a definition of an RMU.) The second was created by the Centre for Resource and Environmental Science (CRES) at The Australian National University. It is created by applying a mathematical procedure to the rainfall data for individual stations that creates an interpolated and smoothed rainfall 'surface' for the whole of PNG (Figure 1.5.2). Both techniques have problems: the PNGRIS map has sudden changes in rainfall along provincial borders and assumes the same rainfall across the whole of an RMU; the CRES map appears to create spurious values when, for example, only one or two rainfall stations are located along a coastline and there are no points inland, or out to sea, for the procedure to work with. Nevertheless, both maps provide a similar picture of the distribution of annual rainfall in PNG.

These maps of the national pattern of annual rainfall (Figures 1.5.1, 1.5.2) show that very high rainfall occurs on three sides of the main highlands valleys: to the west and along both the north and south sides of the main range. High rainfall is also received on the south coast of New Britain and on south Bougainville Island. Very high annual rainfall – over 7000 mm per year – is received from Ok Tedi in the far north-west of Western Province, south-east into northern Gulf Province. Within local areas, rainfall increases with altitude. But over the whole country, altitude is not associated with higher annual rainfall.

Areas where annual rainfall is below 2000 mm occur in the northern part of East Sepik Province, the Markham Valley in Morobe Province, part of the adjacent Ramu Valley in Madang Province, the northern part of Eastern Highlands Province, the southern third of Western Province, the coastline of Central Province, and the Cape Vogel – Rabaraba area of Milne Bay Province.

The ideal annual rainfall for many tropical crops is 1500 mm to 3000 mm (see Section 1.13). Most of the PNG rural population live in places where annual rainfall is in the range 1800–3500 mm. Localities where the annual rainfall is more than 4000 mm tend to be too wet and have too much cloud cover for good agricultural production (see Sections 1.7 and 1.13). Population densities are lower in wetter areas.

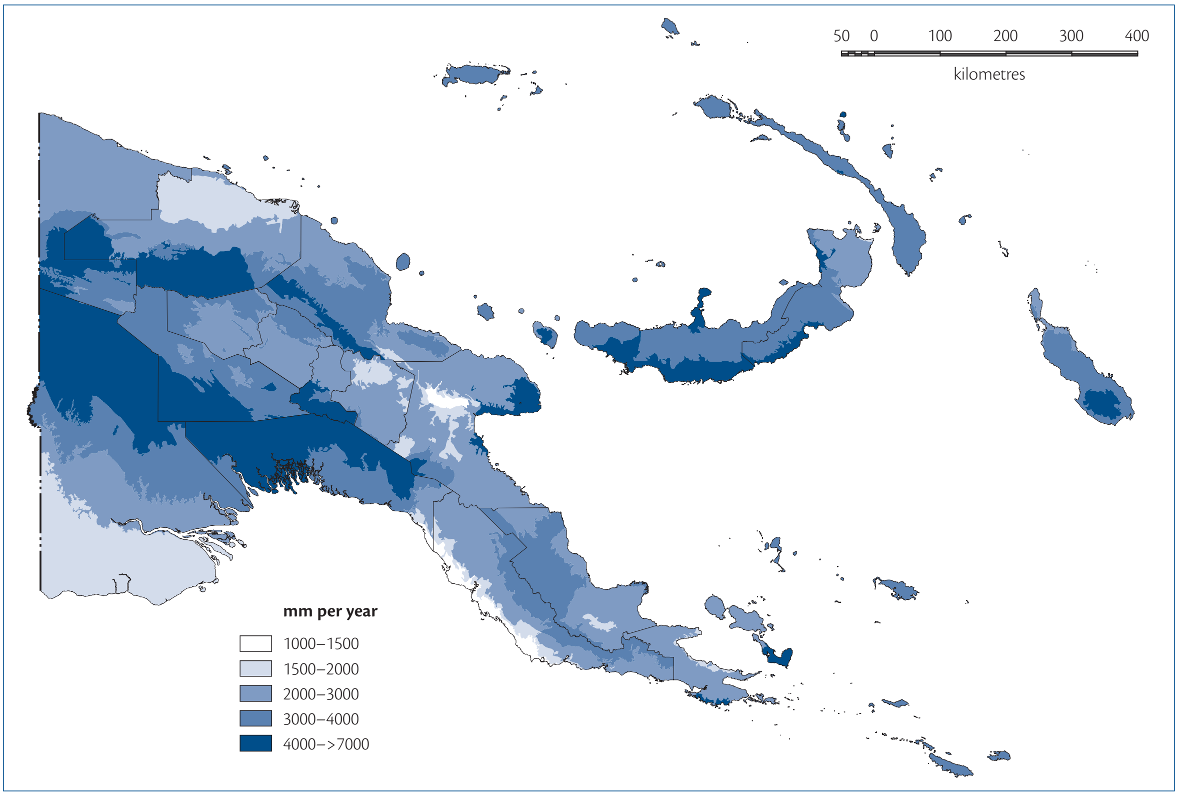

Figure 1.5.1 Annual rainfall from PNGRIS. Source: PNGRIS.

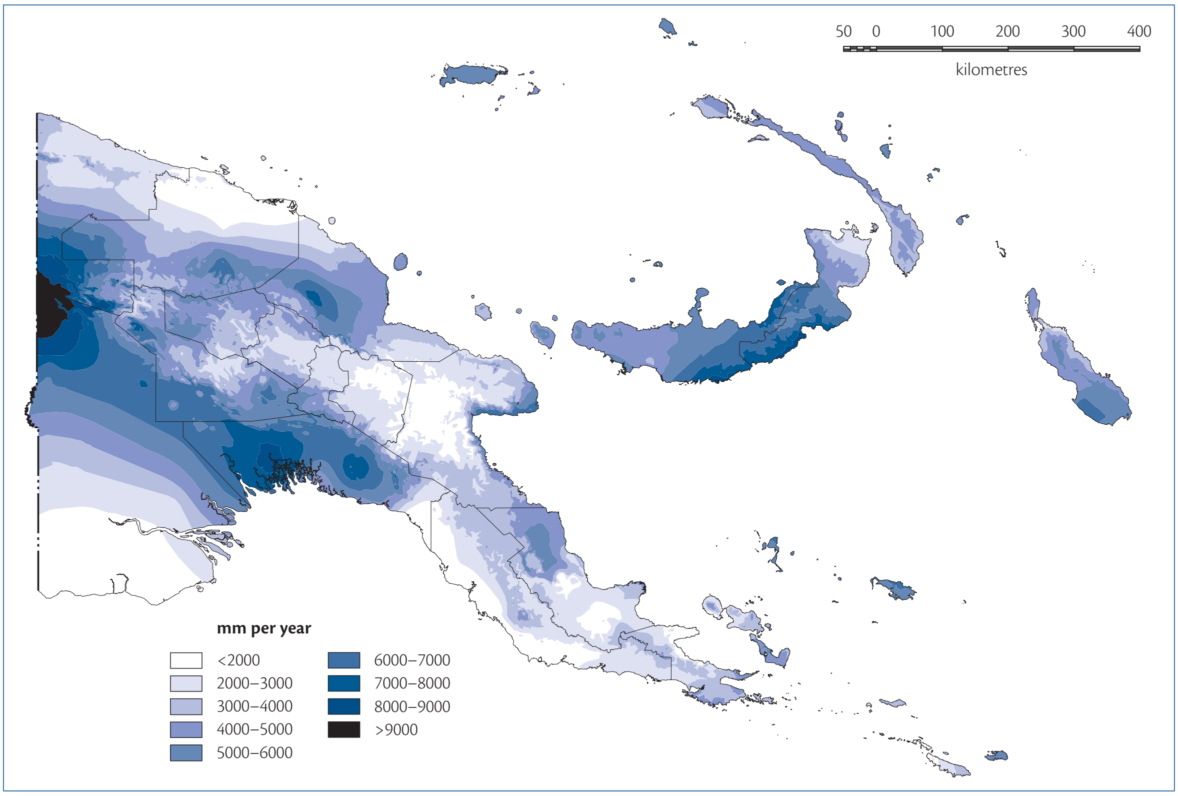

Figure 1.5.2 Annual rainfall from CRES. Source: Centre for Resource and Environmental Science, ANU.

Rainfall seasonality

Most rain falls between January and April in many parts of PNG, with the least falling between May and August. In some parts of the country this pattern is reversed and more rain is received between May and August (Gulf Province, the Huon Gulf around Lae and Finschhafen, the southern part of mainland Milne Bay Province, the southern coast of New Britain and the south of Bougainville Island).

Seasonal rainfall differences can be measured as the relative difference in rainfall between the dry season and the wet season. The most seasonal parts of PNG are the southern half of Western Province, inland and coastal south-east Central Province, the north coast of mainland Milne Bay Province, most of Eastern Highlands Province, and the Markham Valley and north coast of the Huon Peninsula in Morobe Province (Figure 1.5.3).

In other places, rain is received all year round and has no seasonal pattern. There is no seasonal difference in rainfall in the northern part of Western Province, much of Southern Highlands Province, the southern parts of Sandaun and East Sepik provinces, Manus Province, and some of the islands in Milne Bay Province. There are no parts of PNG that are dry all year round.

Rainfall variability and drought

PNG possesses highly reliable annual rainfall that does not vary greatly from year to year for most of the country. Year to year variability is lowest in the highlands.

High rainfall variability occurs in only a few areas: in western Gulf Province, in southern Western Province around the mouth of the Fly River, on East Cape and the islands of Milne Bay Province, and on the south coast of New Britain.

From time to time PNG experiences periods of uncharacteristically low rainfall that are associated with the El Niño Southern Oscillation (ENSO) phenomenon. These events can seriously disrupt food production in PNG (see Section 1.6).

Soil water surpluses and deficits

The amount of water in the soil available to plants is critical to agriculture. Soil water is measured as 'water balance'. Different types of soils can hold differing amounts of water and water can be absorbed or lost from different soils at different rates. The amount of water a soil can hold is known as the 'field capacity' of a soil. The balance of water in the soil (measured in millimetres per day) is the difference between the amount of water entering the soil as rain and the amount of water lost from the soil as evaporation (from the surface) or transpiration (lost from the leaves of plants), or drained downwards through the soil beyond the reach of agricultural plants (Figure 1.5.4). When a soil is capable of absorbing more water (that is, the soil is below field capacity), but no water is supplied by rainfall or irrigation, the water balance is said to be in 'deficit'. When water begins to run off the soil surface and the soil can absorb no more water, it is said to be 'saturated' and the soil water balance is said to be in 'surplus'. Although different soils absorb and lose water at different rates, the most important determinant of soil water surpluses and deficits is rainfall.

Five patterns of soil water balance can be observed in PNG (Figure 1.5.5):

- Regular, seasonal, severe soil water deficits. These occur in the southern part of Western Province and the coast of Central Province, east and west of Port Moresby.
- Irregular, moderate soil water deficits. These occur in the northern part of East Sepik Province, north-west coastal Madang Province, the northern part of Eastern Highlands Province, the Markham Valley in Morobe Province, the Ramu Valley in Madang Province, the central part of Western Province, inland coastal Central Province, parts of Milne Bay Province and the north-east lowlands of the Gazelle Peninsula in East New Britain Province.

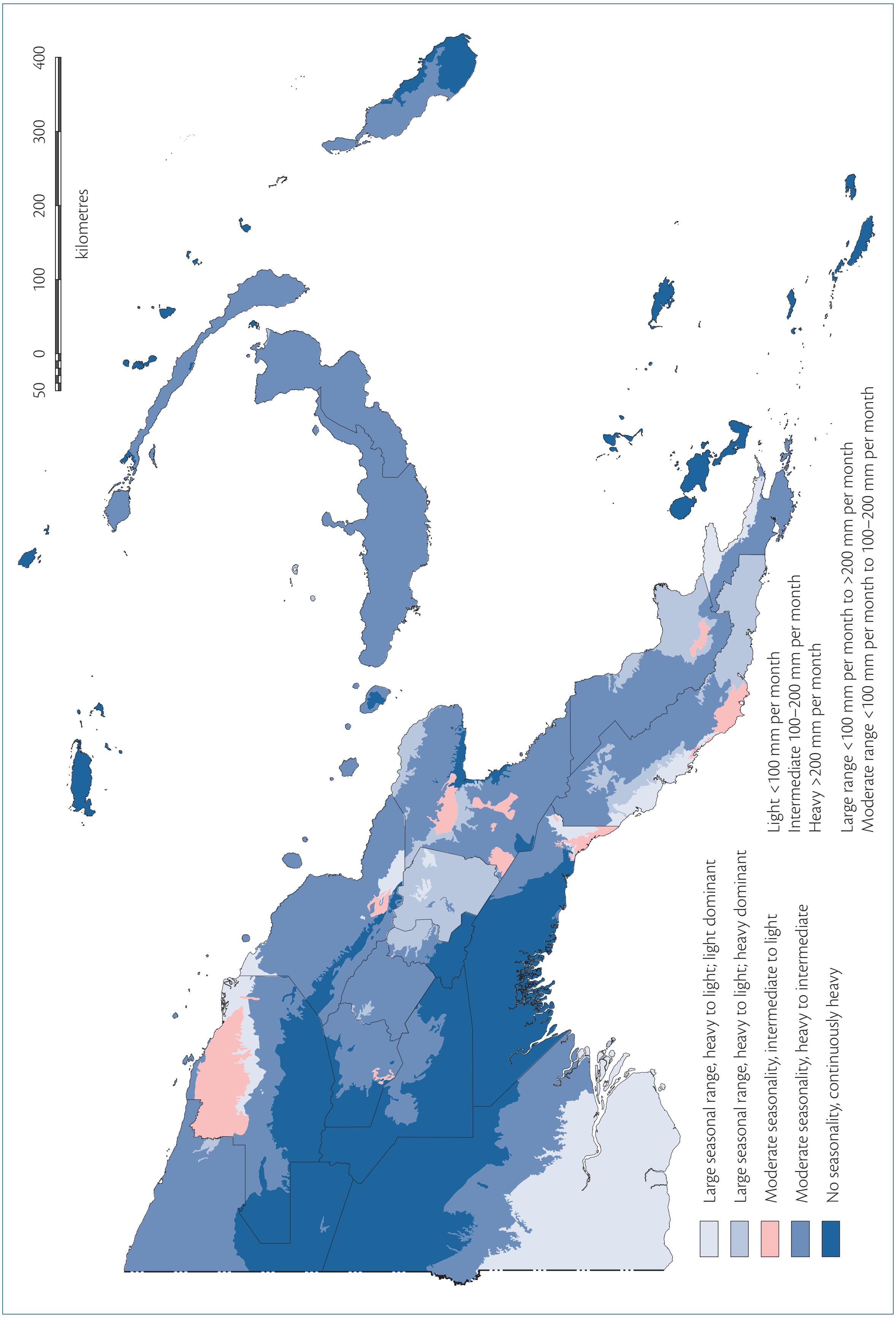

Figure 1.5.3 Rainfall seasonality. Source: PNGRIS.

- Infrequent, slight soil water deficits. This is the pattern over much of the New Guinea mainland lowlands (below 1200 m altitude), on much of the Gazelle Peninsula of East New Britain Province, and on New Ireland Province.
- Rare deficits with moderate soil water surpluses. This is the pattern on the New Guinea mainland at middle altitudes (1200–1500 m) and over much of Manus, New Britain and Bougainville islands.
- Rare deficits with large soil water surpluses. This is the pattern in the highlands of the western mainland, stretching down the southern side of the highlands into Gulf Province, on the eastern end of the Huon Peninsula and along the south coast of New Britain.

These patterns of soil water balance have a strong influence on agricultural systems (see Part 3). Where rainfall is high and regular and soils are usually saturated, digging drains to remove water from the soil and planting certain crops in mounds to raise their roots above the saturated soil is critical for successful agricultural production.

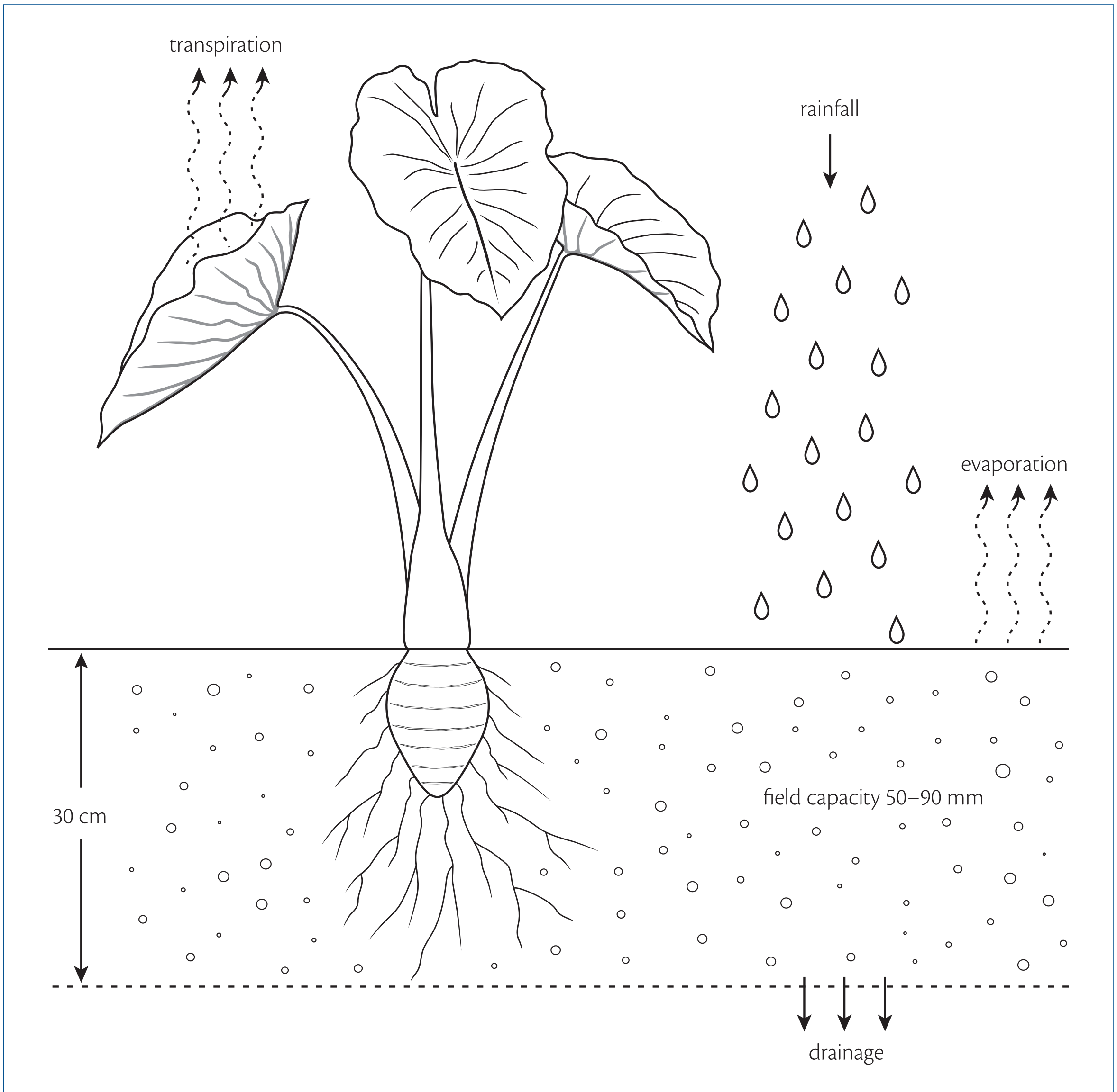

Figure 1.5.4 Water cycle and soil field capacity. Drawing by Catherine Eadie.

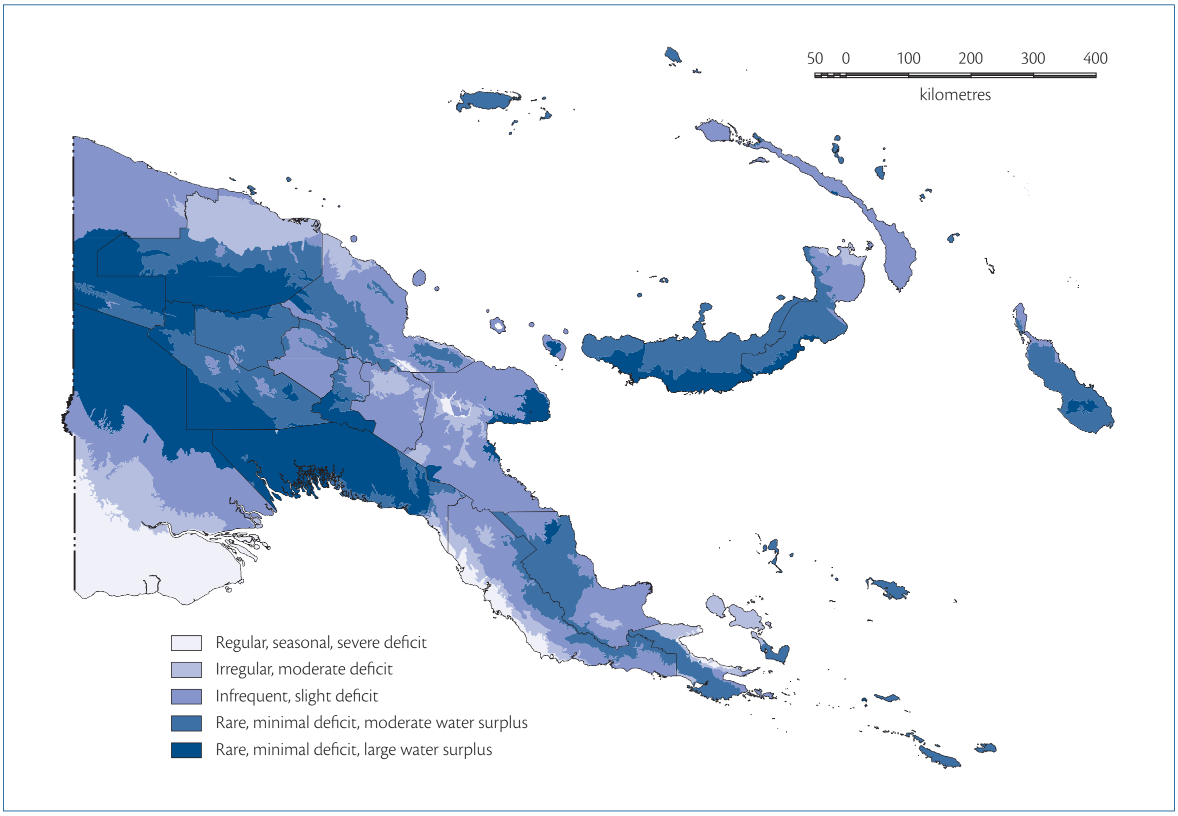

Figure 1.5.5 Soil water deficit and surplus. Source: PNGRIS.

Where regular seasonal soil water deficits occur, a number of techniques are used to overcome the lack of soil water. The most common technique is to plant a mix of different crop species. For example, taro, yam, banana and sweet potato are usually planted together at the start of the wetter months (October–November in places where rainfall seasonality is experienced). This makes food available throughout the year because of the different maturation times of these crops (Figure 1.13.1). Irrigation in PNG was not common and is now only a significant practice in a few villages in the Rabaraba area of mainland Milne Bay Province. It was practised more widely in the past, mostly with taro. The last remnants of such systems are still practised in a few locations such as the Lamari Valley of Eastern Highlands Province and the Kabwum area of the Huon Peninsula.

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1.6 El Niño Southern Oscillation (ENSO) and food supply

The El Niño Southern Oscillation (ENSO) phenomenon is a very important influence on high and low rainfall extremes in PNG. The Southern Oscillation is a global phenomenon in which the temperature of the sea, the air pressure over the sea, and the circulation of air across the oceans move in unison, from one extreme to another (that is, they oscillate).

An El Niño event occurs when the Southern Oscillation moves towards one of its extremes. Extreme El Niño events are associated both with periods of very high rainfall and very low rainfall, usually in a sequence of a period of higher than normal rainfall at the beginning of an ENSO event, followed by a period of lower than normal rainfall and finally a period of higher than normal rainfall as the ENSO event fades away. Excessively wet periods can seriously disrupt food supply but, in a country where rainfall is usually high, the most spectacular disruptions are caused by prolonged droughts.

As well as causing rainfall extremes over large areas of PNG, El Niño events also cause clear skies over what is normally one of the cloudiest countries in the world. Clear skies at night and lower than normal relative humidity allow the heat received from the sun during the day to radiate into the sky at night. Under these conditions, night-time temperatures can fall to below freezing (0 °C) at locations above 2200 m altitude. Succulent plants are damaged by low temperatures and food supply may be disrupted.

The El Niño Southern Oscillation (ENSO) phenomenon

Much of the time, the ocean in the western Pacific and around PNG is warmer than the waters in the eastern Pacific. Warm sea surface temperatures cause low-pressure air to rise over the western Pacific from where it moves east across the Pacific, and descends over the eastern Pacific. This is known as the Walker circulation (Figure 1.6.1).

Under conditions of warm seas and low air pressure, large amounts of water from the sea can be absorbed into the air as water vapour. When this warm, wet air moves over land and rises up over mountain ranges, it cools, and the water vapour in the air condenses and falls as rain. During an El Niño event however, the ocean around PNG becomes cooler than the ocean in the eastern Pacific. The cooler seas cause the air above it to cool and to descend, creating higher air pressure on the surface. As a result, the Walker circulation reverses, and cooler, drier, high-pressure air descends over PNG (Figure 1.6.1). Cooler, drier, higher-pressure air can absorb less water from the ocean. As a result, less rain falls over PNG. In addition, cloud is reduced and skies are clearer, especially at night.

It is possible to study the behaviour of the Southern Oscillation across the Pacific for the past 130 years. Since 1876, the air pressure at sea level has been measured at Tahiti in the eastern Pacific and at Darwin in the western Pacific. Using these two sets of records, the difference between the pressure at Tahiti and at Darwin has been standardised into what is known as the Southern Oscillation Index (SOI).

The SOI is usually a positive number because it is calculated in a way that represents the usual situation in which the air pressure at Tahiti is higher than the pressure at Darwin. During an ENSO event, the SOI becomes negative because the pressure at Darwin becomes higher than the pressure at Tahiti (Figure 1.6.2 shows the SOI during the 1997–98 El Niño event).

Although the SOI is now only one of a number of measures of ENSO, the SOI record allows the past 130 years of ENSO events to be identified and their impacts on PNG examined. Between 1876 and 2005 there were 25 years when the SOI was less than −10 in April and October. In 11 of these 25 years, official reports, newspapers and oral histories describe the occurrence of some or all of the following: wide-spread droughts, repeated frosts in the highlands, severe food shortages, forest fires, and migrations (of people from areas with inadequate food).

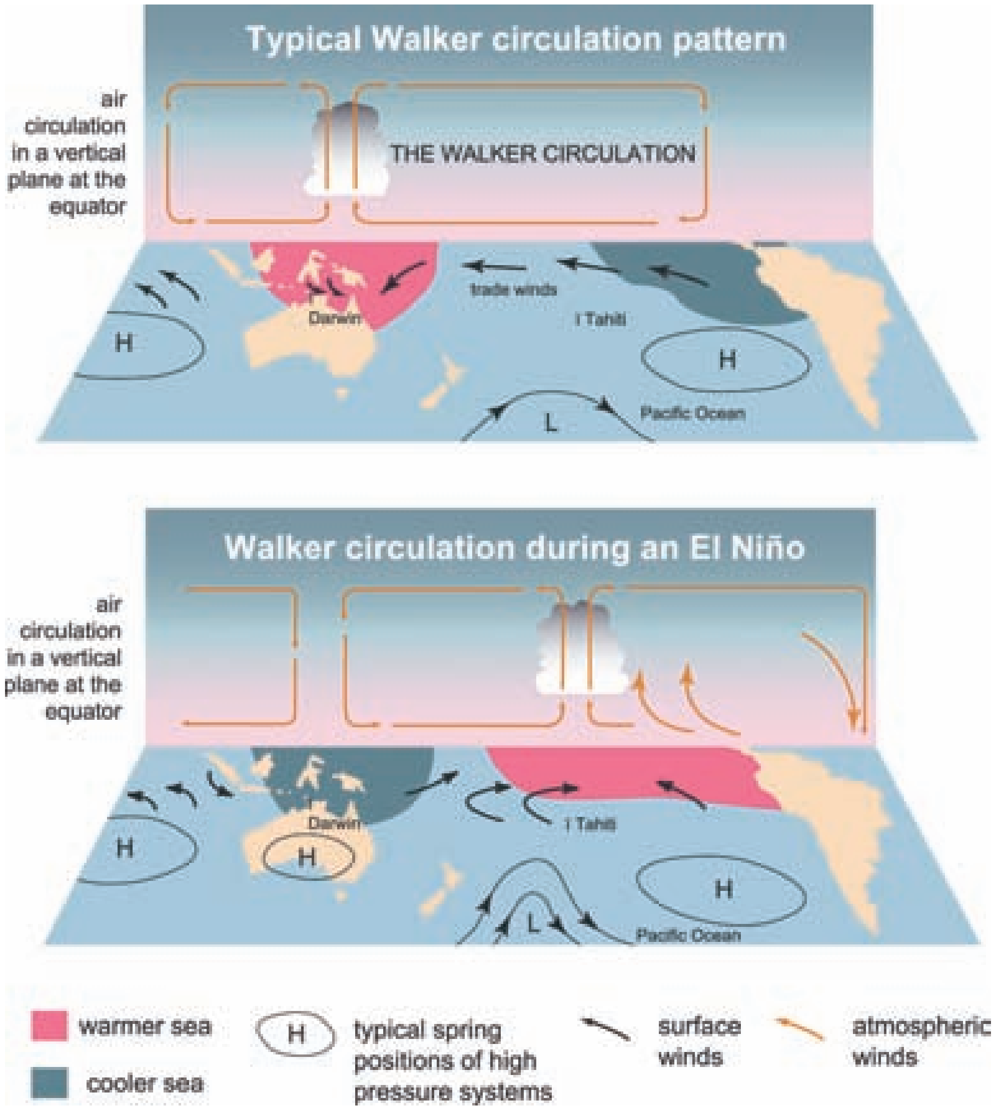

Figure 1.6.1 The circulation of air over the Pacific Ocean and the Southern Oscillation.

Source: Australian Government Bureau of Meteorology website <http://www.bom.gov.au/climate/glossary/elnino/elnino.shtml>. © Commonwealth of Australia, reproduced by permission.

Of these 11 years, there are four years in which all these impacts are reported to be very serious. These years are 1902, 1914, 1941 and 1997.[1] Importantly, not all large ENSO events have severe impacts in PNG. This makes it difficult to predict which particular ENSO event will have a severe impact, but if the frequency of severe impacts since 1876 does not change (with climate change for example), an ENSO event can be expected to have a severe impact on PNG about once every 30 years. This is an average figure and it cannot be used to predict a particular event.

ENSO, food production and famine relief

A strong ENSO event will reduce rainfall significantly in normally wet areas and prolong dry seasons in areas that are seasonally dry, severely reducing food production.[2] Water sources that are used to make sago can dry up and although the larger rivers will continue to flow, the reduction in flow allows salt water from the ocean to invade estuaries, preventing sago production near the coast. At high altitudes, above 2200 m, repeated frosts will completely disrupt food production. In the period preceding the low rainfall, there is often a period of exceptionally high rainfall, which can reduce food production in some systems. In sweet potato systems, the reduction in food supply will occur around 4–5 months after the heavy rainfall.

Most people in PNG have strategies that enable food supply to be maintained during short periods of disruption, including the cultivation of a large number of edible plant species and a knowledge of uncultivated (or wild) edible species that can be collected. However, a severe ENSO event will seriously disrupt the supply of food to large numbers of people over much of PNG for a number of months. Oral histories and colonial reports describe unknown but significant numbers of people dying in the large ENSO events of 1902, 1914 and 1941.

Since at least 1914, colonial administrations have attempted to prevent deaths from starvation during severe ENSO events by the provision of food relief, initially in an unsystematic manner. The first large-scale, systematic provision of food occurred in 1972 following repeated frosts in the PNG highlands. The then Australian colonial administration transported rice, tinned fish and cooking oil into the highlands to prevent what they thought would be a catastrophic movement of starving people out of the frost-affected areas. However, ethnographic research conducted during and after the event showed that migration was a traditional means of coping with frost damage and the migrations were orderly and to places occupied by relatives. Even so, many old people and children are known to have died on the journey through the mountains to the lower valleys.

Following Independence in 1975, the provision of food by government agencies to people said to be starving happened more frequently, particularly in election years, when local political representatives tried to get food delivered to people within their electorates, often on dubious grounds. By the 1990s, requests for food relief by political representatives had come to be viewed with suspicion and cynicism by administrators.

The 1997–98 ENSO event had severe impacts in PNG. By October 1997 it was estimated 150 000 people were eating wild foods and in December this estimate, based on a second nationwide field assessment, had risen to 260 000. A further 980 000 people were assessed to be eating poor quality garden food, in reduced quantities. Many people were forced to walk for hours to collect drinking water of questionable quality. Death rates in some isolated places increased, many schools closed, and many health centres were not staffed and had no medical supplies anyway. In some centres town water supplies were threatened. The hydro-electrical station at Sirinumu, inland of Port Moresby, was forced to stop generating (in order to conserve drinking water in the dam), causing serious power supply disruptions in Port Moresby city. The Ok Tedi mine in Western Province

1 It is possible that 1884 was also a year of severe impacts. The longer ago the event, the less likely it will have been reported. For example, written reports from the Eastern Highlands begin in the late 1930s but they do not begin in the Southern Highlands until the 1950s.

2 South Bougainville Island has a different pattern, and the rainfall tends to be much higher in an ENSO event.

closed for seven months because the Fly River became un-navigable and the Porgera mine in Enga Province closed for six weeks through lack of water for processing operations. The slump in mineral exports resulted in a severe loss of foreign currency to the PNG economy.

AusAID and the Australian Defence Force instigated a relief program that provided food to more than 100 000 people in areas accessible only by air. The PNG national government purchased around 23 500 tonnes of rice for relief in 1997–98 (compared to around 9400 tonnes purchased by AusAID and 7000 tonnes purchased by individual provincial governments), but much of this food was delivered after the most critical period in December 1997 had passed.

Rural people adopted a number of different strategies to survive in the drought:

- They ate 'famine foods'; either foods that are not eaten often, or that are only eaten in times of hunger.
- They raised small amounts of cash by killing and selling pigs, cooking and selling pork and vegetables, buying packets of cigarettes and selling them individually, and by selling artefacts. With the cash earned they purchased imported rice and flour.
- They moved to areas where food was available. It was estimated that in Enga Province up to 75% of people moved out of the high-altitude Kandep and Marient basins during 1997 and walked over mountain passes into the Tsak and Lai valleys. In 1997 however, the drought was so widespread and severe that food in these areas was also critically short. Many people moved further to stay with relatives in towns. For example, an estimated 20–25% of the population from villages at Elimbari in Simbu Province migrated to Goroka, Lae and Port Moresby.
- People employed in urban areas or at mines either sent money to their rural relatives or purchased rice and sent it to them.

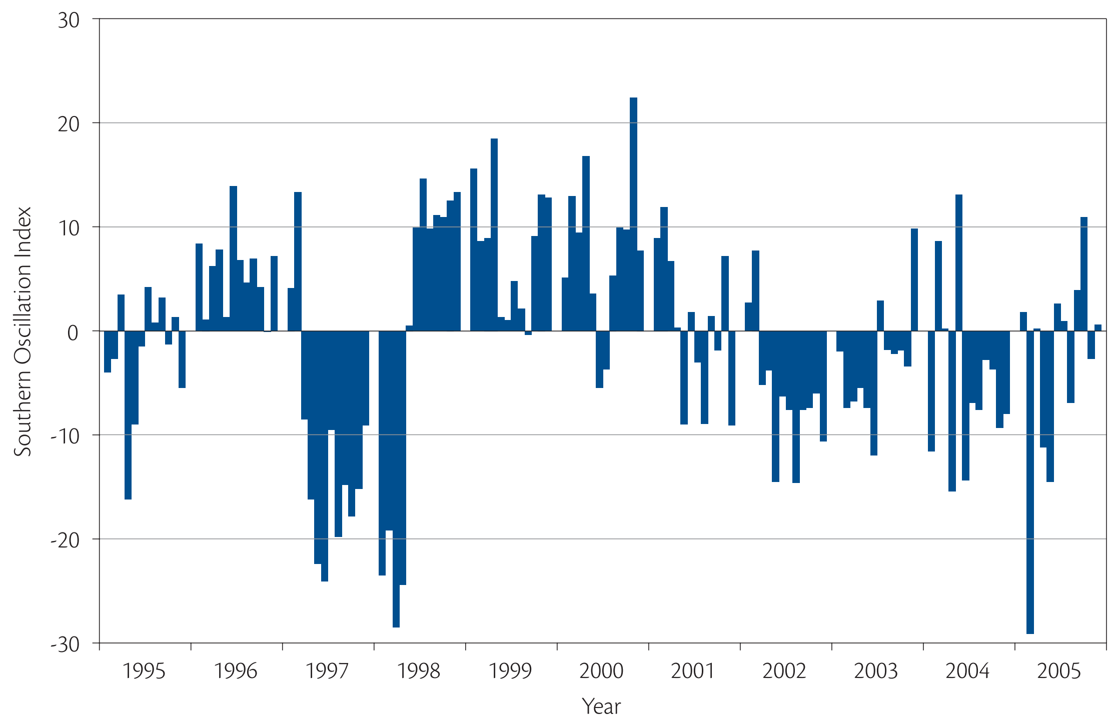

Figure 1.6.2 The Southern Oscillation Index, 1995–2005. Source: Australian Government Bureau of Meteorology website. Data available at <ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/soiplaintext.html>.

Rice imports into PNG during 1997–98 increased by 66 000 tonnes (38%) (see Figure 2.7.1, Table A2.7.1). More than 80% (54 000 tonnes) of this additional rice was sold through retail outlets. It was purchased by people who used their savings or raised small amounts of cash in local markets, and by wage and salary earners who purchased rice for their rural relatives.

Lessons from the ENSO record in PNG

The following are the most important lessons to be learned from the record of the impact of ENSO events in PNG:

- Minor ENSO events occur around every five to six years and may cause local frosts at high altitudes and minor food shortages in the highlands from high rainfall.
- Around every 12 years an ENSO event will have a significant impact on PNG food production because of drought and high rainfall, mainly in the highlands. Widespread frosts may occur. Urban water supplies and electricity generation may be affected.
- Around every 30 years an ENSO event will have a very significant effect on PNG food production all over the country. Sago production will be also affected. Repeated and widespread frosts will occur, completely disrupting food production at higher altitudes. Large bushfires may occur. Urban water supplies and electricity generation will be affected. In isolated areas, the death rate will increase.
- It is not yet possible to predict, with any level of confidence, what severity of impact any particular ENSO event will have on PNG.
- The impact of the 1997 event was worst further away from the equator and in the poorest and most isolated parts of PNG. People with access to earnings from cash cropping or wage labour were generally able to look after themselves, with help from their relatives, by purchasing imported food through retail outlets. Since the 1997 event, their ability to do this may have been significantly reduced by a decline in the value of the kina and a consequent increase in the cost of imported foods.
- When an ENSO event of the severity of 1997 occurs, there is not much people can do to maintain food production. It is not realistic to expect people to protect field crops against repeated severe frosts for months at a time, by covering crops or by setting smoky fires at night.
- Conversely, there *is* much that can be done to assist people to recover after the drought is over. In 1997 impressively large areas of food crops were planted as soon as adequate rain began to fall.
- Overall, food security in PNG is threatened more often by too much water than by too little water. But the food supply problems caused by excessive rainfall are insidious, delayed, difficult to identify and do not affect the whole country at the same time. Food shortages caused by drought are immediate, spectacular and widespread. Contingency planning should take into account threats to food security from all environmental causes, not just from drought.
- People in areas that have a regular dry season use agricultural systems that are adapted to a lack of water for part of the year. They are adversely affected only by very severe ENSO events. People in areas that do not have a regular dry season use agricultural systems that are adapted to deal with excessive water, thus they can be severely impacted by drought.
- Long-term PNG food security strategies, including drought contingency plans, must include the use of imported foods to feed a significant proportion of the population for a short time from time-to-time. But the government need not be directly involved in either the importation or the distribution of this food.

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1.7 Temperature, cloudiness and sunshine

Temperature and light are critical determinants of plant growth (see Section 1.13). In PNG, a country of high mountains, altitude is a major influence on maximum and minimum temperatures and on cloud cover. Cloud cover influences the amount of sunshine available to plants.

Temperature

Altitude has the greatest influence on temperature in PNG. Above 500 m, temperature falls at a regular rate of 0.5 °C for every 100 m increase in altitude, or 5 °C for every 1000 m. This decline in temperature with altitude is known as the 'lapse rate'. The lapse rate causes differences in maximum and minimum temperatures of up to 16 °C over the range of occupied land in PNG, from sea level to 2800 m (Table 1.7.1, Figure 1.7.1).

The average temperature can be predicted for any altitude in PNG. The following formulas can be used to calculate the maximum, minimum and mean temperatures for locations away from the coast (these formulas do not apply to coastal locations). The actual average temperatures may vary a little from those calculated.

$$Y_{max.} = 32.67 - 0.0052\,x$$
$$Y_{ann.} = 27.32 - 0.0052\,x$$
$$Y_{min.} = 22.08 - 0.0052\,x$$

where: $Y_{max.}$, $Y_{ann.}$ and $Y_{min.}$ are mean maximum, mean annual and mean minimum air temperatures (°C) respectively; and x is the altitude in metres

Temperature is also influenced by latitude, or distance from the equator. In PNG, the further away from the equator a place is located, the greater the range in temperatures during the year. In places where the rainfall pattern is reversed (that is, most rain falls between May and September, which is the Southern Hemisphere winter – see Section 1.5), the annual differences in temperature are greater than at locations which receive more rain in January to April or evenly throughout the year (see Table 1.13.1).

Cloudiness and sunshine

Cloudiness influences the amount of sunshine that reaches plants, and the amount of sunshine received by plants influences their growth and productivity. PNG is a very cloudy country (Figure 1.7.2). Between 2 pm and 4 pm from December to February and from June to August, the skies over most of the

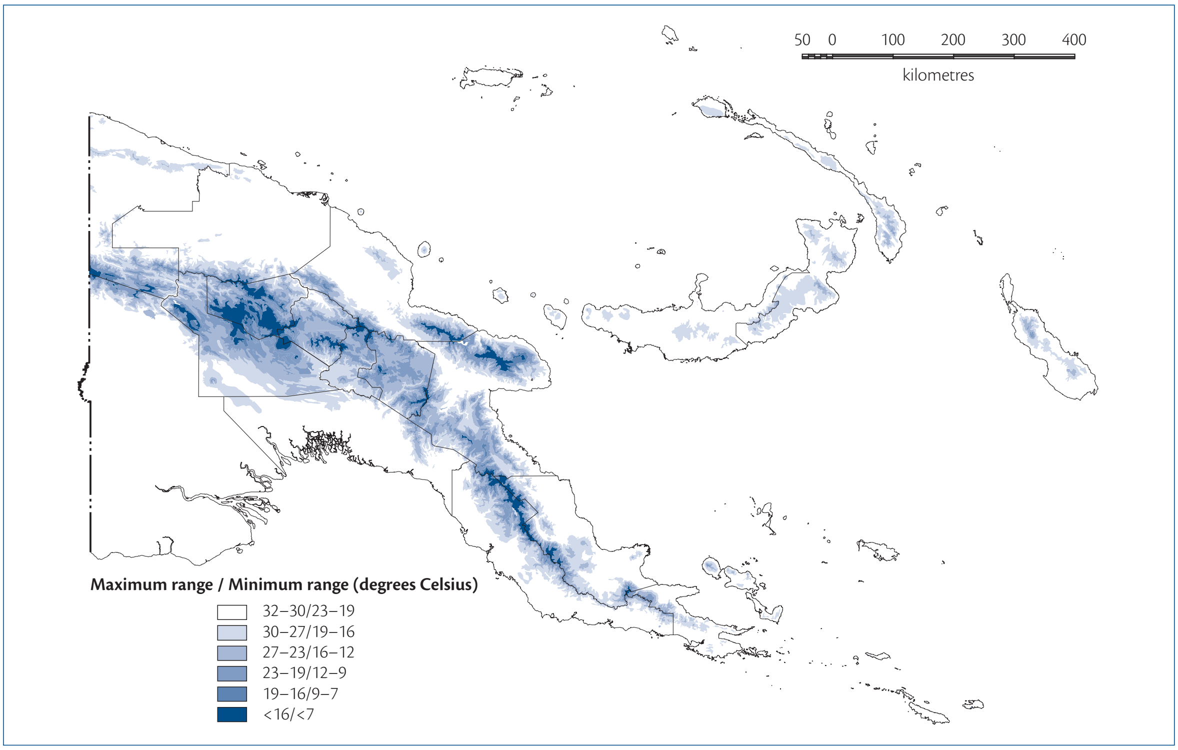

Figure 1.7.1 Generalised temperature zones in PNG in January, based on lapse rates and altitude (°C) (July temperatures are less than 3 °C lower). Sources: McAlpine et al. (1983:95); PNGRIS.

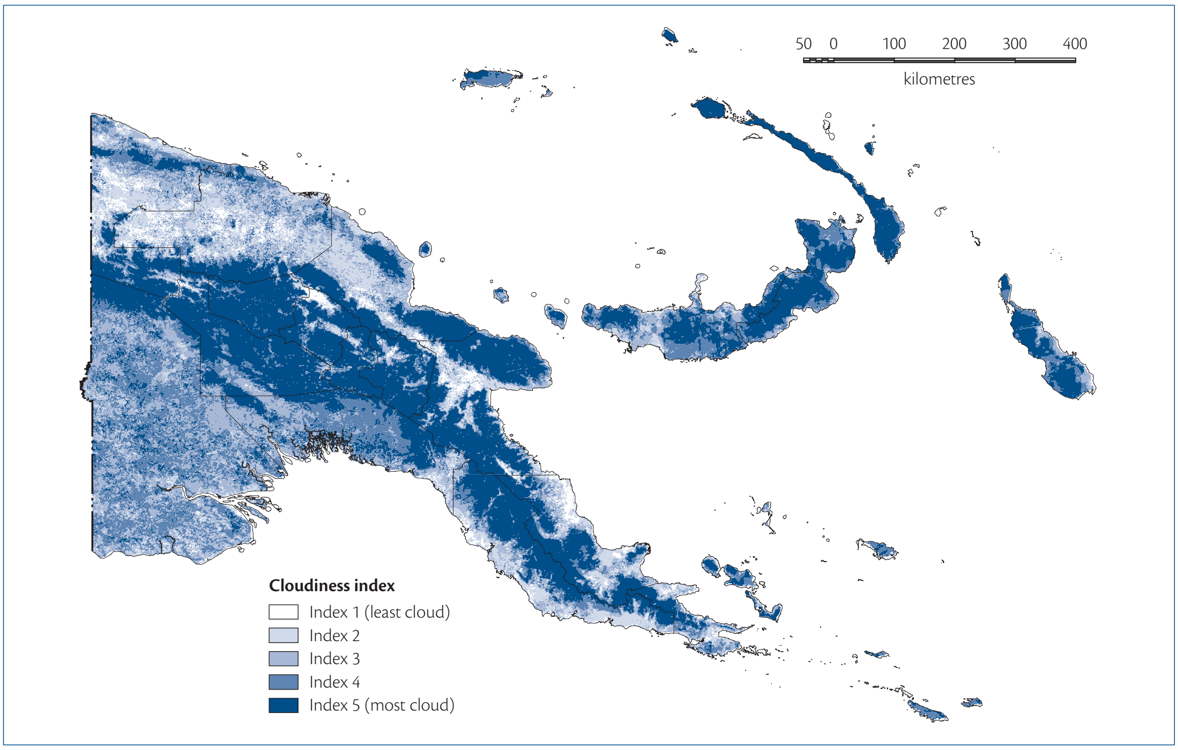

Figure 1.7.2 Cloud cover over PNG, 1997–1998. Source: Developed from a composite set of Advanced Very High Resolution Radiometer (AVHRR) satellite images for twelve months in 1997 and 1998, provided by the CSIRO Division of Land and Water.

Table 1.7.1 Altitude classes and associated maximum and minimum temperatures

Altitude class (metres above sea level)	Maximum temperature (°C)	Minimum temperature (°C)
0–600	32–30	23–19
600–1200	30–27	19–16
1200–1800	27–23	16–12
1800–2400	23–19	12–9
2400–2800	19–16	9–7
>2800	<16	<7

Source: Bellamy and McAlpine (1995:89).

country are up to 63% cloud-covered (five oktas).[1] Mountain areas have consistently heavier cloud cover. In areas of seasonal rainfall, cloud cover is greatest during the wetter season.

In PNG a relationship exists between rainfall, cloudiness and sunshine. The greatest amount of sunshine is received in places with the lowest rainfall. The highlands have less sunshine than other parts of the country. For example, at Goroka in Eastern Highlands Province, sunlight ranges from four hours per day to six hours per day over the year. Nevertheless, most places in PNG are, on average, likely to receive some sunshine every day.

Daylength

The time a plant is exposed to light in a day is called the photoperiod. It is dependent on daylength. There are only small differences in daylength during the year in most of PNG, because the country is aligned east to west just south of the equator. Daylength is influenced by distance from the equator. At Lorengau (latitude 2° S) on Manus Island, the difference between the longest day (in December) and the shortest day (in June) is only 14 minutes. At Port Moresby (latitude 9° 29' S), the difference is 66 minutes. Differences are greater still in the southern part of Milne Bay Province.

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[1] Cloud cover is measure in oktas. One okta is one-eighth of the sky. If the sky is completely covered in cloud, the cloud cover is given as eight oktas, or 8/8. If the sky is half covered, the cloud cover is given as four oktas, or 4/8.

1.8 Climate change

The global climate is changing, almost certainly as a result of human activity. The most commonly reported aspect of climate change is an increase in average temperature, but this is associated with many other changes. This section provides a brief overview of the causes of global climate change; what changes have occurred globally and in PNG so far; and some implications for agricultural production in PNG.

Why the global climate is changing

The earth is a natural greenhouse. Energy from the sun is absorbed by the earth and radiated back into space. But not all of the energy from the sun is lost back into space. The atmosphere, which is made up of a number of different gases, is warmed and so traps some of the heat from the sun. As long as the composition of the atmosphere remains unchanged, the amount of heat gained from the sun and lost again into space remains constant and the temperature of the planet remains relatively stable (Figure 1.8.1). The trapping of heat in the atmosphere is known as the 'greenhouse effect'.

However, it is now clear that the composition of the gases in the atmosphere is changing. The proportions of carbon dioxide, methane and nitrous oxide are increasing. The amount of carbon dioxide in the atmosphere is at a record level. For example, the concentration of carbon dioxide in the atmosphere over the past 400 000 years has been in the range 180–280 parts per million (ppm). It has risen from 270 ppm in around 1850 to 380 ppm in 2005 (Figure 1.8.2). The Intergovernmental Panel on Climate Change (IPCC) reports that the concentration of greenhouse gases is at the highest level for at least 650 000 years. The addition of these gases to the atmosphere is causing it to become warmer. This is because there is a close relationship between the amount of carbon dioxide, methane and nitrous oxide in the atmosphere and the amount of heat the atmosphere can hold and hence the air temperature at the surface of the earth (Figure 1.8.2).

The reason for the changes in the atmosphere is assumed to be human activity. Carbon dioxide is released when oil, petrol, gas and coal (the fossil fuels) are burned. Many sources of energy on the earth involve the burning of these products. Carbon dioxide is also released when forests are burned; when permafrost in the sub-Arctic region melts; and when organic matter is lost from soil as a result of agricultural activity. Methane comes from a number of sources, including wet rice cultivation and digestion of food by sheep and cattle. Nitrous oxide comes from industrial production and losses of nitrogen from fertiliser applied to crops.

Some of the heat in the atmosphere is absorbed by the oceans. So as the atmosphere warms because of the changes in its composition, the oceans also warm and expand (thermal expansion). A warmer atmosphere also causes the ice at poles and in glaciers to melt. The melted ice adds water to the oceans. Thermal expansion and melting ice result in higher sea levels. The rise in atmospheric and oceanic temperatures will cause changes in global wind patterns. These three things, warmer air, warmer seas and changes in wind patterns, may cause changes in rainfall and snowfall. Annual rainfall could increase or decrease or the time of the year when rain is received might change. These changes could also result in a change in the number and severity of extreme climatic events, including more cyclones and episodes of very high rainfall or drought.

Most of our understanding of the climate is based on analyses of records of the climate in the past. Prediction of climate in the future is based on mathematical models developed from these analyses of climatic records. The accuracy of these models is not yet known and different models give somewhat different predictions, but all models predict more warming and significant changes to the climate.

Global climatic change so far and predictions for the future[1]

Firstly, a short overview of changes in global climate up to now and IPCC predictions for future global change is given. The next section focuses on what we know from PNG.

Global temperature

Global mean temperatures have risen 0.8 °C since the late 1800s. However, the trend is not linear and rates of increase in surface temperature are greater after the mid 1970s. From 1979 to 2005, the linear trend was 0.16–0.18 °C per decade, giving total warming of 0.46 °C since 1979. The year 2005 was one of the warmest two years on record.

Changes in extremes of temperature are also consistent with warming of the climate. There has been a widespread reduction in the number of frost days in mid-latitude regions, an increase in the number of warm extremes, and a reduction in the number of daily cold extremes. The most marked changes are for cold nights, which have become rarer over the period 1951–2003 for most of the land regions studied. Warm nights have become more frequent across most of the same regions. Diurnal temperature range (the difference in temperature between day and night) decreased by an average of 0.07 °C per decade over the period 1950–2004.

A summary of all expert assessment for the future is that warming is likely to be in the range 2.0–4.5 °C, with a likely value of about 3 °C by 2100 compared with the period 1980–2000. A temperature rise of 2.0–4.5 °C may not sound very much. But even at the coldest period during the most recent ice age, about 15 000 years ago, the average temperature of the planet was only about 5 °C colder than the present climate. So the increase in temperature in the next 100 years could be as much as the difference between the average global temperature some 15 000 years ago and the present. The average temperature in New Guinea was also about 5 °C colder than the present climate about 18 000 years ago.

Global rainfall

Over the past 30 years (since 1976) there has been a downward trend in rainfall in the tropics between 10° south and 10° north, but this is a very uneven trend. It seems that there has been an increase in the number of heavy rainfall events in many regions of the globe, even in those places where a reduction in total rainfall has occurred.

Droughts have become widespread in various parts of the world since the 1970s. In Australia and Europe, direct links to global warming have been inferred through the extreme nature of high temperatures and heat waves accompanying recent droughts. More generally, decreased rainfall and higher temperatures that increase evaporation and transpiration are important factors that have contributed to more regions experiencing drought (see Figure 1.5.4 for an illustration of these terms).

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1 Information in this section is taken from the Intergovernmental Panel on Climate Change Draft Fourth Assessment Report. This is due for official release in 2007 after peer review and was made available in May 2006 on a US government website. The IPCC has operated since 1988 and reports about every five years. The working groups are composed of experts in climate and related fields, and their papers are subject to rigorous peer review.

Global warming models predict that rainfall will generally increase in the tropics and over the tropical Pacific in particular, with general decreases in the subtropics, and increases at high latitudes. The intensity of rainfall events is also predicted to increase, particularly in tropical and high-latitude areas that experience increases in mean rainfall. Annual rainfall is likely to increase slightly in the southern Pacific; however, this is a regional prediction and the outcome could be quite different at different locations in PNG.

Global sea level rise

The mean sea level rose in the second half of the 20th century at 1.8 mm per year (Figure 1.8.3). Projections of global average sea level rise for the 21st century due to thermal expansion and melting ice are in the range 130–380 mm by 2100. Thermal expansion will make the greatest contribution to sea level rise.

Most climatic models predict that sea surface temperatures will be warmer in the central and eastern Pacific near the equator, compared with the western Pacific, that is, an El Niño-like response (see Figure 1.6.1). This suggests that PNG and other western Pacific locations will experience more droughts, but there are considerable uncertainties with these predictions.

Climate change in PNG

The data on climate in PNG presented in this book (Sections 1.5, 1.6, 1.10 and 1.11) is largely based on climatic data recorded prior to 1970. Less information has been recorded over the past 30 years, but enough information exists to conclude that the climate is changing in PNG as it is elsewhere in the world. This can be inferred from direct measurements of

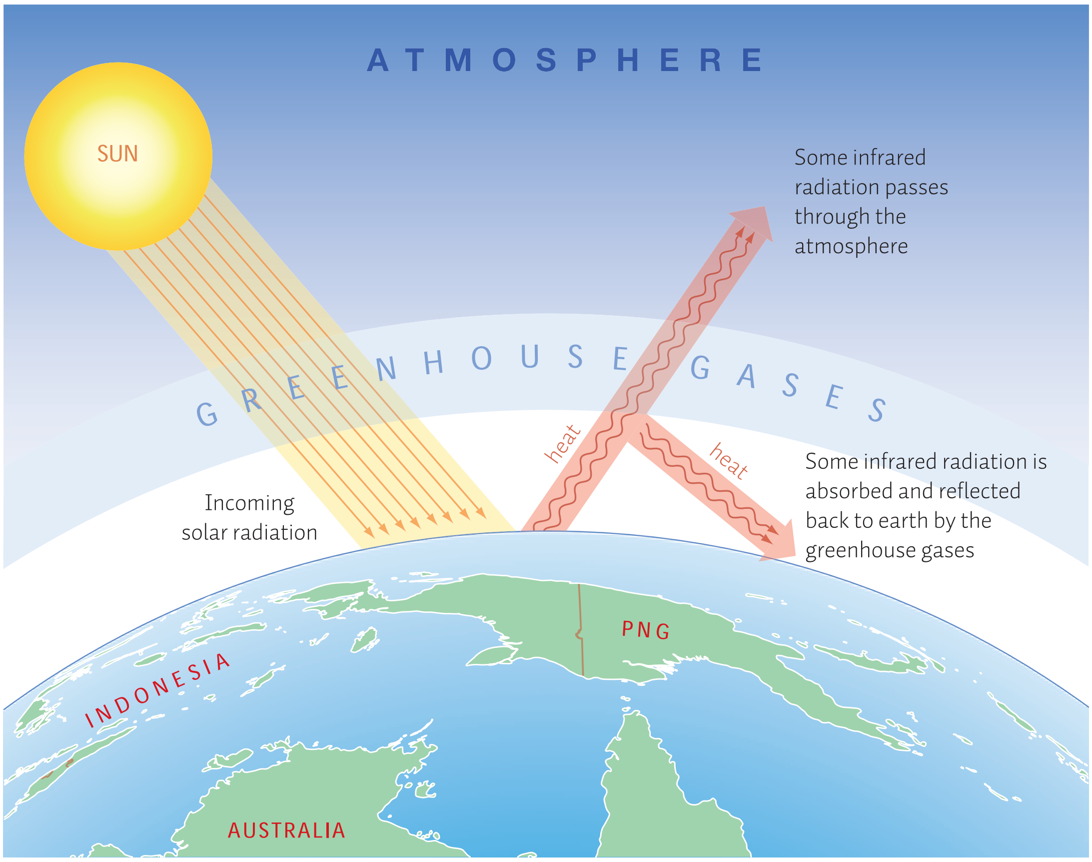

Figure 1.8.1 The greenhouse effect. Source: Cartographic Services, ANU.

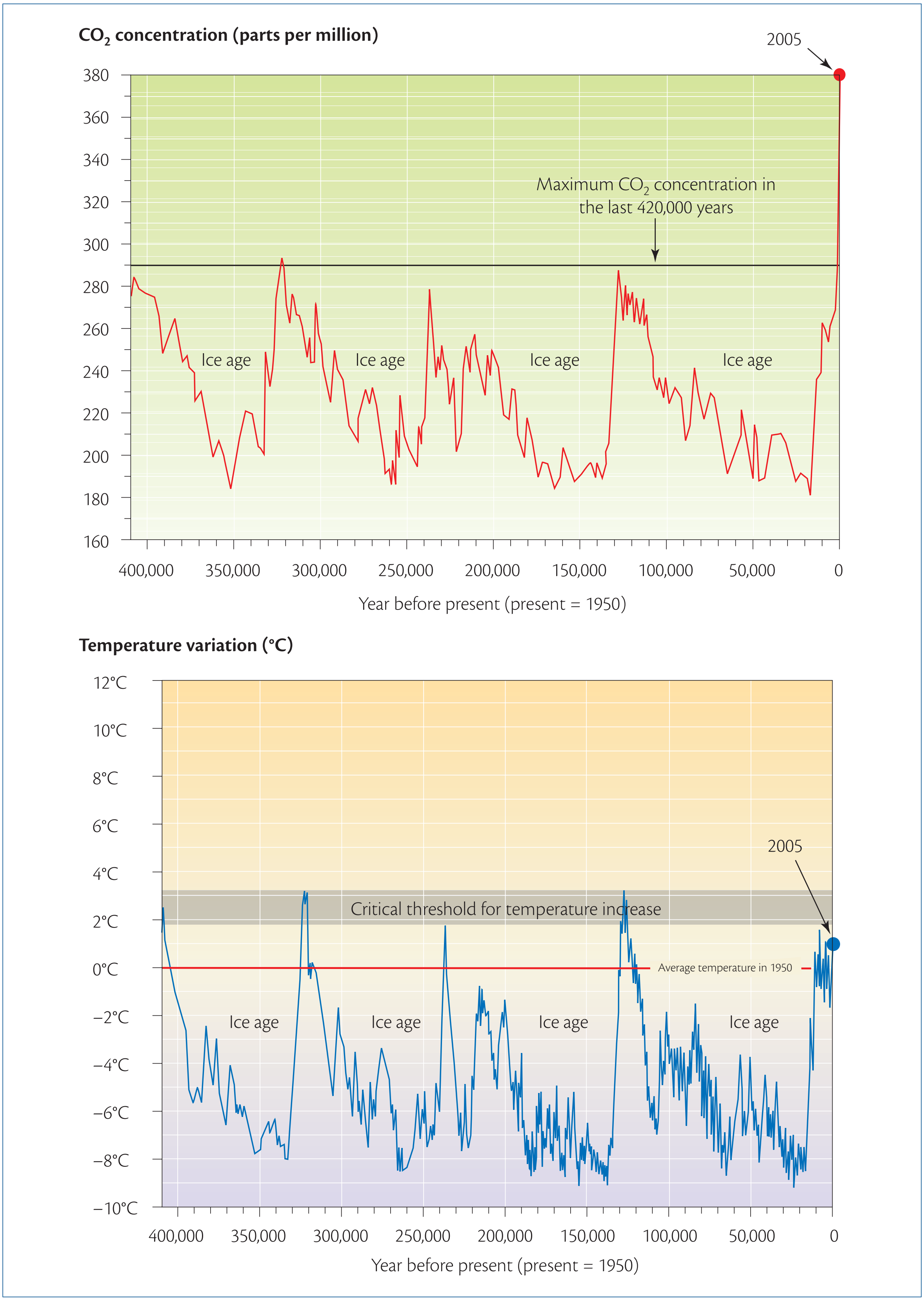

Figure 1.8.2 Record of carbon dioxide concentrations and average global temperature over the past 400 000 years.
Sources: UNEP/GRID-Arendal (2006) and <http://monde-diplomatique.fr/cartes> from data in Petit et al. (1999). Graphic design: Philippe Rekacewicz.

temperature and rainfall, observations of crop growth made by villagers and scientists, and extrapolation from nearby locations, including Indonesia and Australia.

Temperature in PNG

Studies of temperature change in PNG have found that temperatures increased during the 20th century, with most of the increase occurring from about the mid 1970s. An important finding from an agricultural perspective was that the rate of temperature increase was greater for minimum than for maximum temperatures.

An analysis of temperature change from nine coastal locations found that minimum, mean and maximum air temperatures had increased by an average of 0.2 °C per decade. The trends from three of these sites – at Port Moresby, Madang and Kavieng – are illustrated in Figures 1.8.4 and 1.8.5. The rate of temperature increase and the faster rise since the mid 1970s in PNG are similar to the global trends described earlier. Temperatures tended to be lowest in El Niño years and higher in La Niña years that followed. Only limited long-term temperature data runs are available for highland stations in PNG, but they show similar trends to the lowland stations. For example, at Aiyura in Eastern Highlands Province, maximum temperature increased by 0.75 °C (0.3 °C per decade) over the 25 years 1977–2001 (although the daily minimum did not increase over this period).

Another clear indication that temperatures are increasing in the highlands comes from observations on the upper and lower altitudinal limits of crops (Figure 1.13.3). For example, between 1980 and 1984, the author observed coconuts bearing up to an average altitude of 1000 m. Coconuts grew up to 1700–1800 m in the highlands, but did not bear nuts at those altitudes. Occasionally, they had very small nuts at altitudes as high as 1310 m. By the year 2000, coconuts were bearing very small nuts at up to 1450 m altitude in at least three highland valleys. This suggests that temperatures in the highlands have increased by about 0.7 °C over 20 years, which is consistent with the changes in maximum temperature recorded at Aiyura.

Highland villagers also report that crops have been bearing at higher altitudes since around the mid 1990s. As well as coconut, they say that betel nut, mango and breadfruit are now bearing where the trees previously grew but did not bear. Such changes have been documented at a village at about

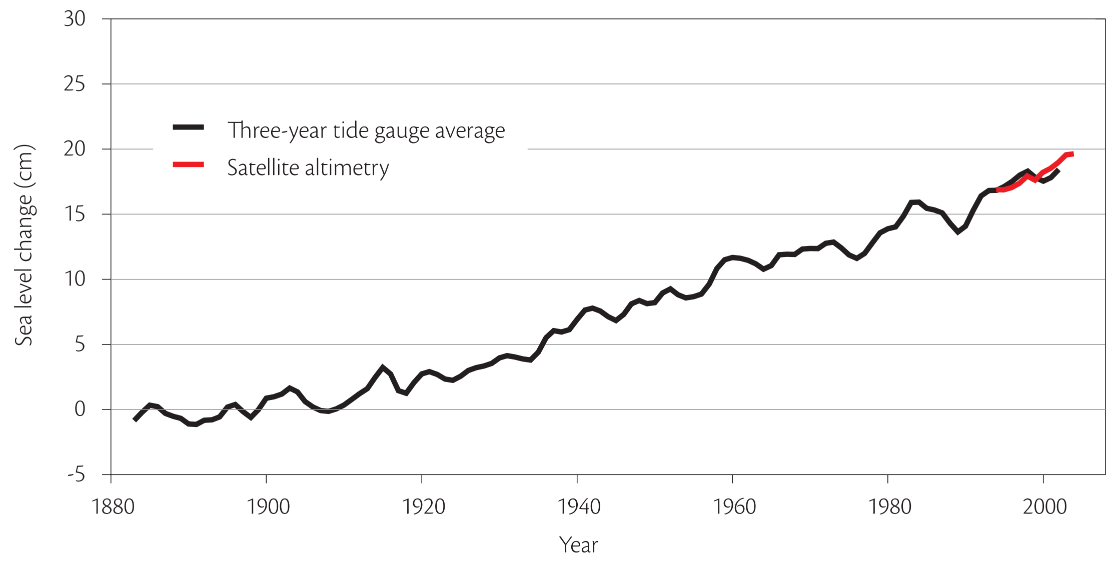

Figure 1.8.3 Global mean sea level rise, 1883–2002. **Note:** The tide gauge data spans 1883–2002 and the satellite altimetry data spans 1993–2004. Source: Robert A. Rohde / <http://www.globalwarmingart.com/>.

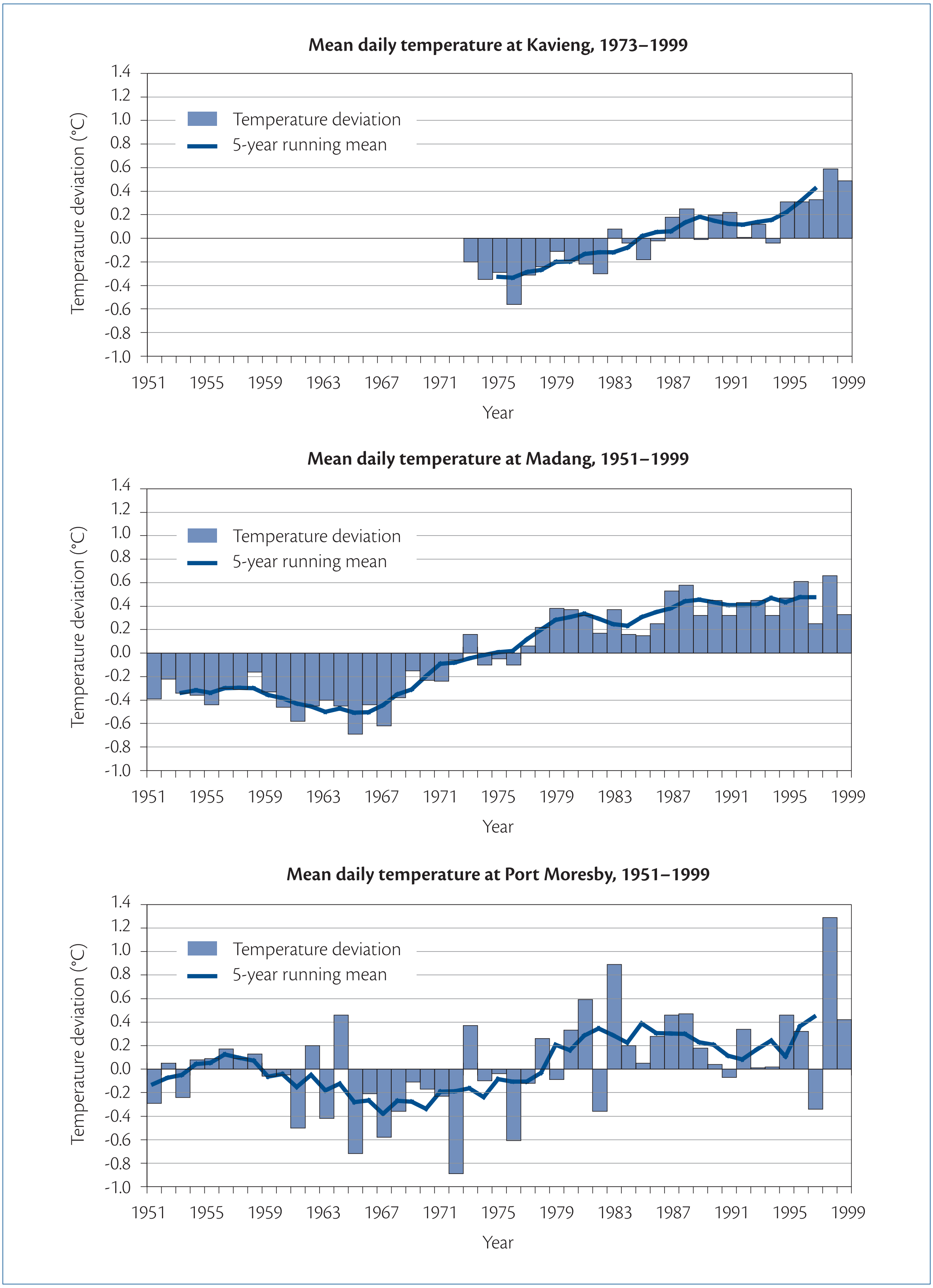

Figure 1.8.4 Temperature increases at Kavieng (1973–1999), Madang (1951–1999) and Port Moresby (1951–1999).
Note: Temperature deviation is the difference between the mean temperature for any one year from the long-term average for the entire period. Temperature data for Kavieng for the years 1951–1972 was not available.
Source: Bourke et al. (2002).

1900 m altitude near Teptep on the Huon Peninsula. Villagers there believe that the climate has warmed in the decade prior to 1988. It had become possible to grow *marita* pandanus and a cultivated palm by the late 1980s. Previously, these crops could only be grown at lower altitudes. In addition, a bird species that was previously found only at lower altitudes had moved into higher altitude locations.

Rainfall in PNG

There is less evidence for changes in rainfall patterns in PNG over the past 30 years. The majority of rural rainfall recording stations in PNG ceased recording around 1980, leading to a loss of information about rainfall. An analysis of monthly rainfall patterns at Goroka in Eastern Highlands Province from 1946 to 2002 found that there had been a shift to longer, but less pronounced, rainy seasons. Throughout the lowlands and highlands, villagers report similar changes in rainfall patterns. People say that seasonal rainfall patterns (see Section 1.5) have changed or are less predictable. They generally do not report an overall increase or decrease in rainfall. But because rainfall is already high at most locations in PNG, it is unlikely that villagers would notice an increase or decrease unless it was very large.

Sea level rise in PNG

There is much anecdotal evidence for rises in sea level in PNG. For example, a study of agriculture in Bougainville Province reported that villagers in many islands believed that the sea was eroding the coastline and that these changes had commenced some 30–40 years ago. In the Mortlock Islands, villagers were concerned about poor growth of their staple food, swamp taro, in some of the taro pits on the islands. They believed that sea water was invading the underground freshwater lens in which the swamp taro was growing and was responsible for the poor growth in some plots. A similar report was made by villagers on Ontong Java, north of Malaita Island in Solomon Islands. Other reports of encroachment by

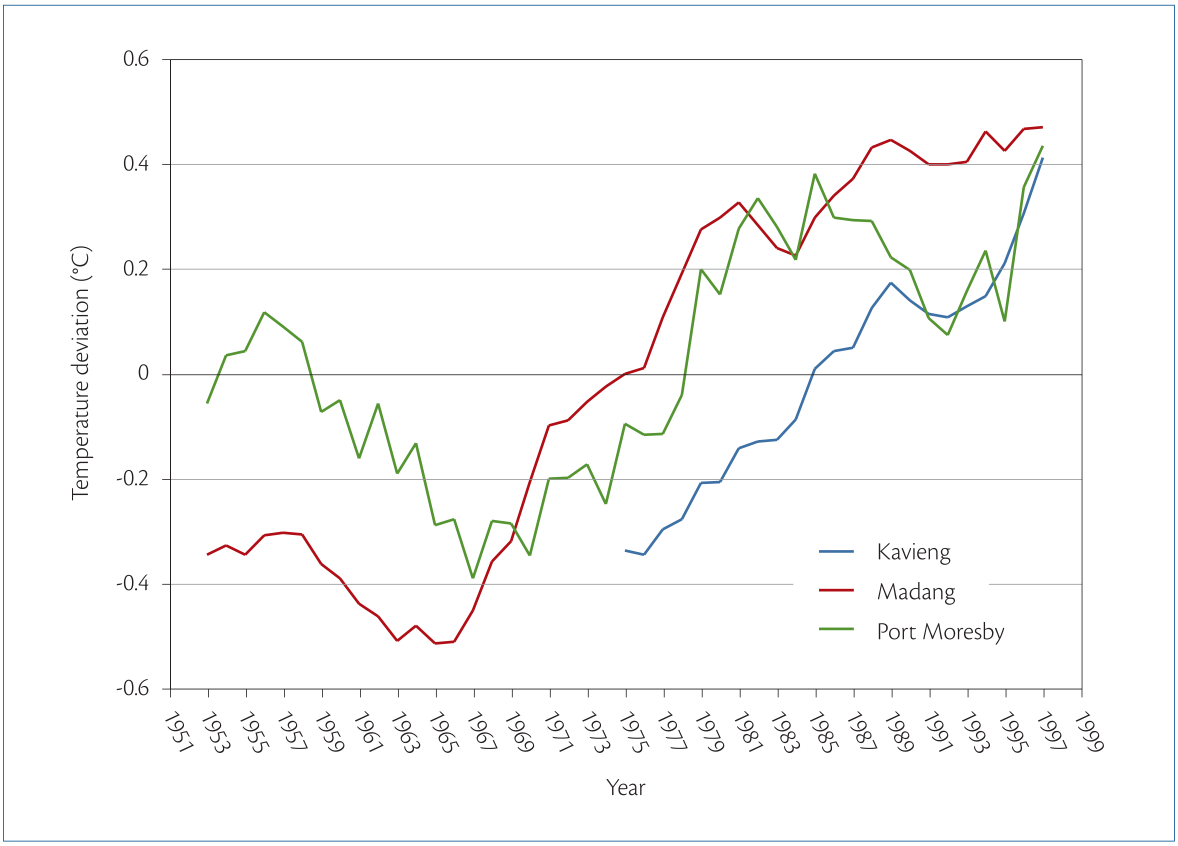

Figure 1.8.5 Temperature increases at Kavieng (1973–1999), Madang (1951–1999) and Port Moresby (1951–1999) (5-year running means). Source: Bourke et al. (2002).

the sea in recent years come from the Murik Lakes in East Sepik Province, along the Wewak waterfront, some small islands in Manus Province, and along the coast in Gulf and Western provinces.

However, caution is advisable in attributing the changes in shorelines to sea level rise. The Duke of York Islands off the north-eastern coast of East New Britain Province are reported to be swamped by rising sea levels. In fact, these islands are sinking because of tectonic (volcano-related) activity. Tectonic movements can cause land to rise as well as fall and are the reason why land at nearby Rabaul is rising. Elsewhere, sea level rise is blamed for other causes of failure of food supply. People in the Carteret Islands in Bougainville Province suffer from chronic food shortages because of a very high population density (see Table 1.3.1) and shortage of land for food gardens. In late 2005, plans were made to move the islanders to Bougainville Island (they had previously been relocated in the early 1980s, but returned to their islands some years later). Newspaper reports described the Carteret islanders as 'some of the world's first climate change refugees'. In fact, their problems are caused by the highest population density anywhere in PNG and having a mainly subsistence economy, rather than by rising sea levels.

In summary, there is much evidence from direct recordings, the bearing pattern of certain plants and villagers' observations that average temperatures have increased in the lowlands and highlands of PNG, particularly since the mid 1970s. There are indications that the distribution of rainfall within the year has changed, if not the total rainfall. There are also indications that rises in sea level are having an impact on shorelines and growth of crops on atolls.

Implications for agriculture in PNG

Climatic change is already influencing agriculture in PNG but, in most cases, it remains difficult to predict what outcomes will be. This is because we do not know enough about probable changes in patterns of rainfall and rainfall extremes. Furthermore, agricultural responses to climate change will be complex, and will depend on how people respond, as well as the responses of plants. For example, an increase in temperature might make coffee rust more severe in the highlands, but this impact could be reduced if the rainfall and humidity was reduced. Conversely, the impact could be greater if the rainfall increased as well as the temperature. This impact would be reduced if villagers adopted improved rust control techniques or rust resistant coffee varieties.

Temperature and agriculture

Increases in minimum and maximum temperature are already having a small influence on agricultural production and will have a greater influence in the future. Some tree crops are bearing at higher altitude in the highlands. Given the direct relationship between altitude and temperature in PNG (see Section 1.7), it is likely that many crops will be able to be grown at marginally higher altitudes in the future and so the areas where they can be grown will expand. However, the lower altitudinal limit of some crops, such as Irish potato, Arabica coffee and *karuka* (*Pandanus julianettii* and *P. brosimos*), will increase because of increasing temperatures (Figure 1.13.3).

Sweet potato is the most important food crop in PNG and provides almost two-thirds by weight of the staple food crops (see Figures 2.2.1 and 2.2.3). It is an important food in many lowland locations as well as throughout the highlands. Tuber formation in sweet potato is significantly reduced at temperatures above 34 °C. Maximum temperatures in the lowlands are now around 32 °C, so an increase of 2.0–4.5 °C within a hundred years could reduce sweet production in lowland locations, perhaps within one or two generations.

Diurnal temperature ranges also have an important influence on productivity (see Section 1.13). In PNG, the diurnal temperature range is greater in the highlands than in the lowlands, and is one reason why crop yields are higher in the highlands. The IPCC reports that, for most of the planet, diurnal range decreased over the period 1950–2004. If this is also occurring in PNG, it will tend to reduce crop yields to an unknown extent. It is likely that overall temperature increases will marginally reduce productivity in the lowlands and in the main highland valleys, but will marginally increase productivity at locations above 2000 m.

Increases in temperature may also change the incidence of some diseases, especially those influenced by rainfall and humidity. Taro blight, caused by the fungus *Phytophthora colocasiae*, is less severe in PNG at a few hundred metres above sea level than at sea level, and is rarely found above an altitude of 1300 m. The fungus is sensitive to temperature and a small rise in temperature could mean that the fungus would reduce taro yield at higher altitudes than occurs now. Similarly, coffee rust is present in the main highland valleys at 1600–1800 m, but does little damage there. It is a problem for coffee production at lower altitudes, below about 1200 m. So again, a rise in temperature is likely to increase the altitude at which coffee rust has a severe impact on coffee production.

Changes associated with El Niño Southern Oscillation (ENSO) events are not known. If ENSO events occur more often as models predict, more frosts will result at high-altitude locations (above 2200 m) (see Section 1.6). This will have an adverse impact on agricultural production.

Rainfall and agriculture

The IPCC prediction is for higher rainfall in the South Pacific, including PNG. Rainfall patterns in PNG are complex (see Section 1.5) and it is likely that any changes in rainfall patterns will also be complex and so difficult to predict.

With a few exceptions, most places in PNG receive high annual rainfall. In the lower-rainfall areas, an increase in rainfall and reduced seasonality of distribution would be beneficial for agriculture. However, for most of PNG, an increase in total rainfall and a less seasonal distribution would have a negative impact on agriculture. The most vulnerable locations are those where rainfall is already over 3500 mm per year.

If ENSO events become more common, more droughts could result as well as more episodes of very high rainfall. However, the likely changes in the pattern of ENSO events are not well understood. Another outcome of increased rainfall would be greater cloudiness and less bright sunshine. If that was to occur, it would probably reduce crop productivity, especially where cloud cover is already very high (see Section 1.7).

Sea level rise and agriculture

There are indications that rising sea levels are already having a minor negative impact on very small islands and other coastal locations because of coastal erosion. Rising sea water is also possibly contaminating the freshwater lens on atolls where swamp taro is grown. Rising sea levels do not necessarily cause very small islands to be covered by sea water: coral reefs respond to rising sea level by growing upwards, and the extra coral sand may cause the islands to rise. Nevertheless, it is quite possible that a rapid rise in sea levels will cause major problems for villagers living on very small islands and in other low-lying coastal locations, such as in the Gulf of Papua.

In the Pacific, attention has focused on small island states such as Tuvalu. However, there are about 100 000 people in PNG living on what have been defined as 'Small Islands in Peril'. These are about 140 islands smaller than 100 km^2 in size and with population densities greater than 100 persons/km^2. It is these people who are likely to suffer the most severe consequences of rising sea levels.

Other implications

There are implications from climate change in PNG that are not considered here. These include human health, especially malaria incidence in the highlands, water supply, fish availability, and health of coral reefs and other marine ecosystems.

Climate change is going to alter the global economy in coming decades and some of these changes are likely to impact, positively and negatively, on PNG. Such changes could include a reduction in availability of fossil fuels; a greater demand for biofuels from oil crops such as oil palm and coconut; increased demand for hydro-electricity (which is potentially abundant in PNG) for industrial uses; and carbon trading whereby companies pay for trees to be planted on a large scale to absorb carbon dioxide. Some of these changes present economic opportunities that could be beneficial for PNG.

It is known that a higher level of carbon dioxide in the atmosphere results in increased photosynthesis and decreased evaporation and transpiration. This is a positive for crop production. Given that atmospheric carbon dioxide is at record levels and is forecast to keep increasing, plant productivity is likely to increase. However, possible benefits are likely to be offset by decreases in productivity caused by higher temperatures and altered rainfall patterns.

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1.9 Soils

There are five major soil-forming factors: climate, vegetation, slope, parent material and time. Changes in the combination of these factors can result in soils varying over relatively short distances. Soils are also significantly influenced by human activities, for example, by tillage, composting, mounding or erosion caused by cultivation on steep slopes. As a result, it is difficult to generalise about soils and their properties in PNG.

PNG soils are relatively young, particularly in areas where sedimentation is occurring or volcanoes are depositing ash. These young soils have a fair potential for agricultural production because they can provide adequate amounts of water and nutrients to plants.

Soil classification in PNG

Knowledge on the distribution of soils and their abilities to support plant growth is essential for managing agricultural production. In PNG, most villagers have names for their soils and they are knowledgeable about soil properties. In textbooks and publications on soils in PNG, the Soil Taxonomy classification system of the United States Department of Agriculture (USDA) is used. USDA Soil Taxonomy uses measurable properties of a soil, including soil depth; colour; texture (e.g. sand, sandy loam, loam, clay); structure (e.g. blocky, granular, crumb, columnar); consistency (e.g. sticky, porous); soil water balance (see Section 1.5); and soil chemical properties such as pH (a measure of acidity) and the ability to retain nutrients. These properties are used to group soils into classes. A full classification under the USDA Soil Taxonomy requires chemical and physical analyses.

PNG uses the USDA Soil Taxonomy because it is closely linked to the development of the Papua New Guinea Resource Information System (PNGRIS; for further information see Section 1.15). An internationally recognised soil classification system has advantages when exchanging information; however, some problems occur when USDA Soil Taxonomy is used to classify PNG soils. USDA Soil Taxonomy relies heavily on laboratory analysis, which is expensive. Many of the previous analyses of PNG soils do not have sufficient analytical data to allow a full USDA Soil Taxonomy classification. In addition, soil moisture and soil temperature information is needed in USDA Soil Taxonomy, but only limited data are available for PNG soils.

Information on the soils of PNG is available in PNGRIS. The information in PNGRIS covers the whole of PNG. It was created by using information from soil surveys in particular places and predicting the soil types that will occur in the PNGRIS resource mapping units (RMUs) by using the associations that occurred in the soil surveys between parent material, rainfall, inundation and slope. (See Section 1.15 for a definition of an RMU.) PNGRIS lists three possible soil types in each RMU, depending on the relative area of each soil. PNGRIS cannot be used to produce detailed soil maps and should not be used above a scale of 1:500 000. The map in this section is based on only the first-listed soil in PNGRIS RMUs[1] (Figure 1.9.1).

In USDA Soil Taxonomy, the highest level is soil order. The following soil orders occur in PNG:

- **Entisols** – very young soils, with little or no profile. These soils occur mainly on recent alluvium or on steep slopes where soil erosion takes place.
- **Histosols** – soils that contain very high levels of organic matter (peat soils). These soils are mostly dark brown to black in colour, and occur in swampy areas. They are saturated with water for much of the year.
- **Inceptisols** – moderately weathered soils, with no strongly contrasting horizons. They include soils derived from volcanic ash.
- **Andisols** – volcanic ash soils. These soils are very important in PNG. They do not appear in PNGRIS, where they are classed with Inceptisols. In Tables A1.9.1 and A1.9.2 and Figures 1.9.2 and 1.9.3 they are included with the Inceptisols. However, in Figure 1.9.1 a class called Andisols has been created by mapping from PNGRIS soils that are derived from lightly weathered volcanic ash.
- **Vertisols** – soils with high clay content that are sticky when wet and very hard when dry. These soils swell when wet and crack when dry and are generally of high fertility. They are not common in PNG.
- **Mollisols** – soils in which there is accumulation and decomposition of organic matter. These soils generally have a high base (e.g. calcium, magnesium) content.
- **Alfisols** – moderately weathered soils that have an argillic horizon (a soil layer with higher clay content due to movement of clay from the top to lower layers). These soils are usually highly fertile.
- **Ultisols** – strongly weathered and acid soils with an argillic horizon. These soils have a low base saturation and are usually relatively infertile.
- **Oxisols** – very strongly weathered soils, with low fertility. These soils occur on old land surfaces and are not common in PNG.

The distribution of soils in PNG

The most common soils in PNG are Inceptisols (with Andisols), which are found over almost half of the total land area (Figures 1.9.1, 1.9.2, Table A1.9.1). Inceptisols cover more than 80% of the land area of Western Highlands, Simbu, Eastern Highlands and West New Britain provinces. Inceptisols are least common in Western, East Sepik and Gulf provinces.

The next most common soils are Entisols. These young soils cover more than a quarter of the total land area, reflecting the high geological activity that occurs in PNG. Entisols are common soils in East Sepik, Gulf, Morobe, Central, Western, Oro, Sandaun and Madang provinces.

Ultisols (strongly weathered soils) cover approximately 14% of the land area of PNG, and occur mainly in Western Province, where they occupy more than half of that province. Alfisols are common in New Ireland where they cover over a quarter of the land area. Mollisols are most prevalent in East New Britain, where they occur on a third of the land area.

[1] In PNGRIS, soils information is mapped into mapping units that are defined by attributes other than soils (landform, rock type, altitude, relief, rainfall, inundation, province). This means that more than one soil can occur in an RMU. PNGRIS deals with this by allowing each RMU to have up to three soils. Soils that cover less than 20% of an RMU are not listed. If only one soil is listed it covers around 80% of the RMU area. If two soils are listed, the first covers 40%–60% of the RMU and the second 20%–40%. If three soils are listed, the first covers 30%–50% of the RMU area and the second and third 20%–40%. The information presented in this section is based on *only* the first soil listed. Thus the figures presented in Tables A1.9.1 and A1.9.2 are approximations.

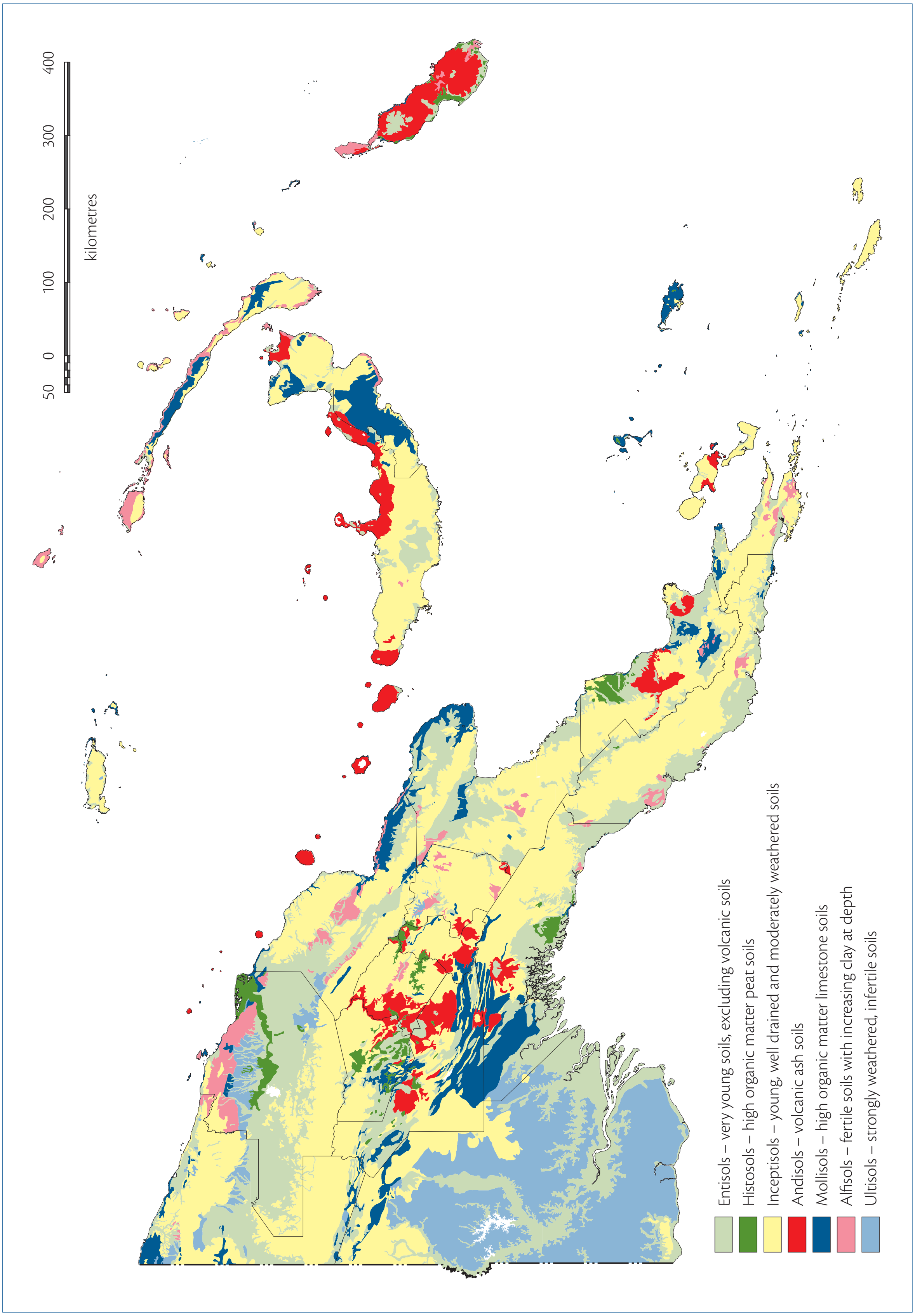

Figure 1.9.1 Distribution of USDA Soil Taxonomy soil orders. **Note:** The areas covered by Vertisols and Oxisols are too small to be shown on the map (see Table A1.9.1). Source: PNGRIS.

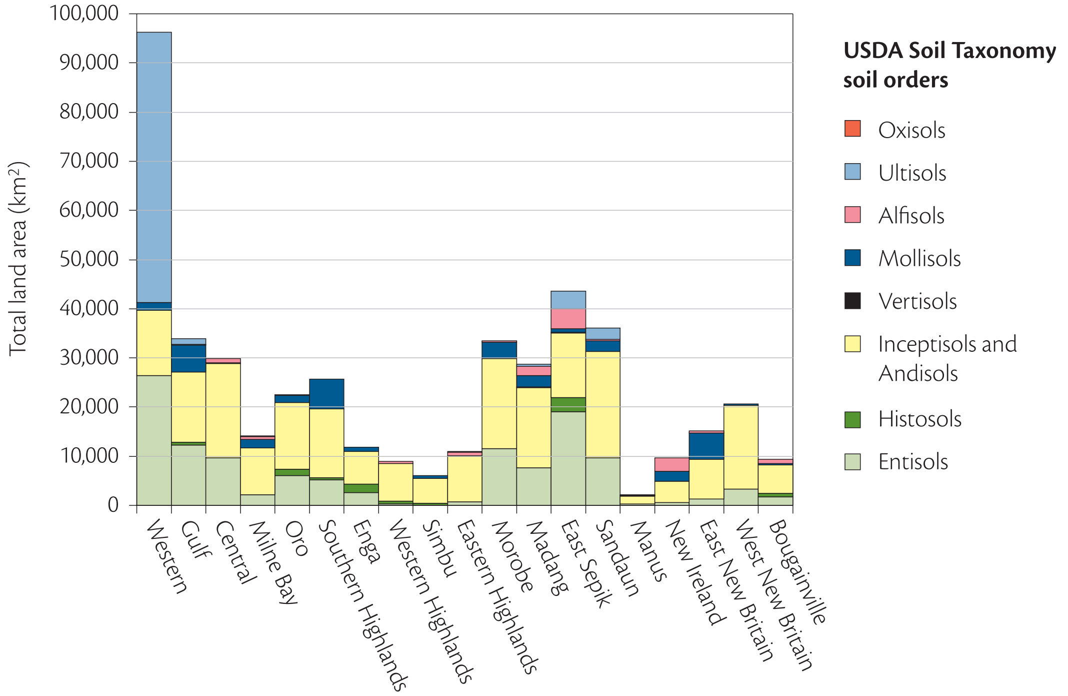

Figure 1.9.2 Distribution of USDA Soil Taxonomy soil orders by land area and province. Source: PNGRIS.

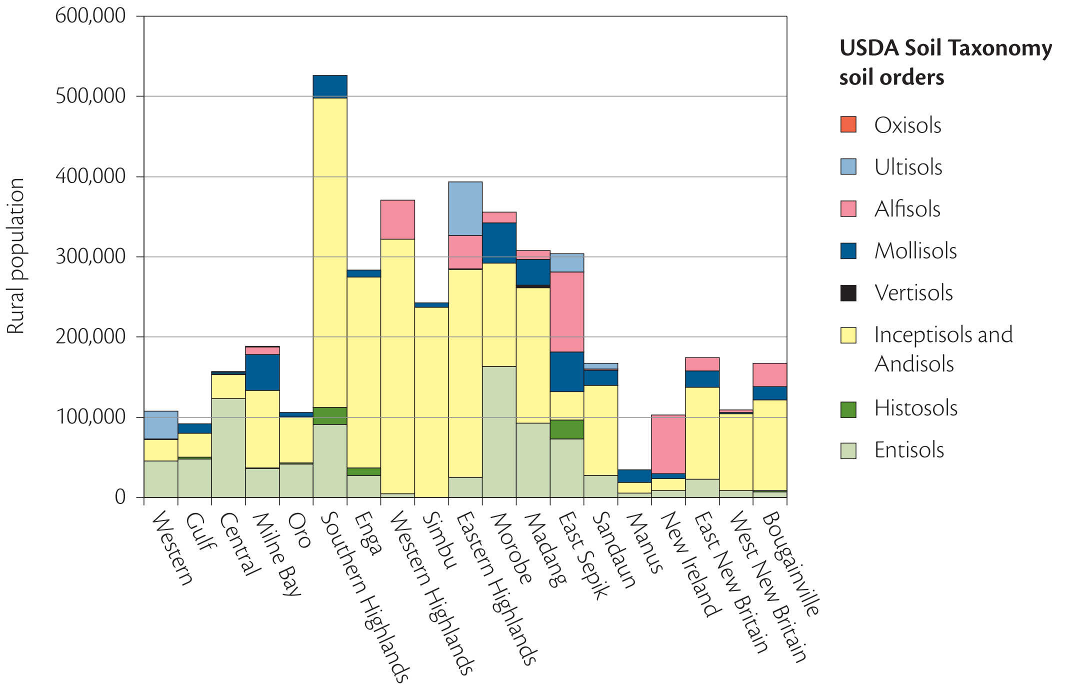

Figure 1.9.3 Distribution of USDA Soil Taxonomy soil orders by rural population and province. Sources: NSO (2002); PNGRIS.

People and soils

This section discusses the numbers of people who live on the soil orders described above. As the distribution of soils is complex, the information presented here can be used only as a general indication of the importance of particular soils to the wellbeing of people in PNG. Landform, climate and other factors also help to determine the distribution of people (see Sections 1.10, 1.11 and 1.12).

Almost 2.5 million people (59%) of PNG's rural population live on Inceptisols (Figure 1.9.3, Table A1.9.2). Inceptisols (with Andisols) support more than 80% of the populations of Simbu, West New Britain, Western Highlands and Enga provinces. Entisols support 20% of the population and are most important in Central Province, where 78% of the provincial population use these soils. Alfisols and Mollisols together support a further 16% of the rural population. Alfisols are important in New Ireland Province and Mollisols are important in Manus Province. Around 32% of the population in Western Province, and 17% of the population in Eastern Highlands Province, cultivate Ultisols. Although Ultisols are usually relatively infertile, those in Eastern Highlands are well-drained, humus-rich, reddish Ultisols that occur mostly on old stable surfaces. These Ultisols have few available minerals but are able to support a large population (66 500 people on 226 km^2) because of their structure and the practice of intensive tillage.

Soil nutrients

The availability of nutrients for plants depends on several factors. Low levels of nutrients in the soil may be caused by low amounts of nutrients in the parent material from which the soil is derived. The nutrients may also become chemically fixed in the soil and so not available to plants. Nutrient imbalances (for example, high calcium, low potassium) in the soil may have a similar effect. High rainfall can leach nutrients from the soil. Low nutrient levels may also result from cultivation, when agricultural crops remove nutrients which are then not replaced by humans or by natural processes.

Soil nutrients that plants require in relatively large amounts are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). A number of other elements required in very small amounts by plants are called micronutrients, and include boron, zinc, manganese, iron and copper. Nutrient deficiencies affect crop production in PNG. This problem is likely to worsen in the future as population increases and land is used more intensively.

Soil nitrogen availability is determined in part by the length and type of fallow (see Section 3.8), the introduction of organic matter (plant materials) into the soil (see Sections 3.10 and 3.11), and climate (rainfall and temperature) (see Sections 1.5 and 1.7). Most nitrogen in PNG soils is derived from organic matter. Soil nitrogen tends to be higher in highlands soils, where temperatures are cooler and organic matter decomposes more slowly.

In PNG soils the availability of phosphorus is also dependent mostly on the organic matter content. A small part comes from the weathering of parent material or secondary minerals. Phosphorus is usually found in combination with calcium, magnesium, iron and aluminium. Although relatively large amounts of total phosphorus may be present in the soil, little may be available to plants because it combines with other elements (iron and aluminium) and becomes insoluble, or 'fixed' in the soil. Phosphorus fixation is widespread in the volcanic ash soils that support large numbers of people in the highlands, and in Oro and Bougainville provinces (Table A1.9.2). Phosphorus fixation can also be severe in Ultisols and Oxisols.

The availability of soil potassium is related to rock type and the mineralogy and the stage of weathering of the soil. Potassium-deficient soils are usually highly weathered and leached with limited amounts of mineral reserves. Volcanic ash soils usually have high levels of potassium. Soils that develop on limestone and that have high levels of calcium and magnesium may have a potassium deficiency because the calcium holds the potassium in the soil and makes it unavailable to plants. This is common, for example, in New Ireland Province.

Research on nutrient deficiencies of agricultural crops started in the 1950s, but little active research is being carried out now on soil nutrient deficiencies or on soil nutrient management strategies in PNG. Soil nutrient problems exist in parts of the country. Further intensification of land use will affect soil fertility, and nutrient deficiencies are therefore likely to increase, particularly in food crops where inorganic fertilisers are not being used.[2] There is a need to monitor the development of nutrient deficiencies as well as to properly identify them through trials and soil and foliar (leaf) analyses.

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[2] Organic fertilisers include animal manure, compost and mulch made from leaves (see Section 3.11). Inorganic fertilisers are usually manufactured, for example, urea, potassium chloride or mixed nitrogen, phosphate and potash fertiliser. Most organic fertiliser is not purchased in PNG, whereas most inorganic fertiliser is purchased. Most of the inorganic fertiliser used in PNG is applied to export tree crops or to commercial crops grown for the domestic market, such as sugar cane (see Section 5.19).

1.10 Landforms and altitude

Landforms

Landforms are the structural features of the landscape. Landforms have a direct relationship to relief and slope and, in turn, determine rates of erosion, runoff and whether land is flooded. Landforms influence agricultural land use.

The PNG landscape can be divided into five basic landforms (Figure 1.10.1):

- Mountains and hills (not of volcanic origin).
- Landforms of volcanic origin (including volcanic foot slopes and plains).
- Plains and plateaus.
- Floodplains.
- Raised coral reefs and littoral areas (beach ridges, tidal flats, mangrove swamps and other coastal features).

The following summary points can be made about these landforms in PNG:

- Around half (52%) of the total land area of PNG is mountains and hills; almost 19% is plains or plateaus; 18% is floodplains; and a considerably smaller proportion is volcanic landforms or raised coral reefs and littoral areas (Table 1.10.1, Table A1.10.1).
- The provinces with the greatest proportion of total land area comprising mountains and hills are Enga (91%), Eastern Highlands (90%), East New Britain (83%), Simbu (79%), Central (78%) and Morobe (77%).
- Almost two-thirds (63%) of the land used for agriculture in PNG (see Section 1.2) is on mountains and hills; 12% is on volcanic landforms; 11% is on plains and plateaus; and 9% is on floodplains (Table 1.10.1, Figure 1.10.2, Table A1.10.2).
- The provinces with the greatest proportion of land used for agriculture on mountains and hills are Eastern Highlands (91% of land used for agriculture), Enga (90%), Simbu (86%), Madang (76%), Sandaun (76%), Morobe (76%) and Gulf (75%).
- Volcanic landforms used for agriculture are most important in Bougainville Province, where 61% of land used for agriculture is of volcanic origin. This is also a significant landform for agriculture in Oro (46%) and Southern Highlands provinces (32%).
- Although 59% of the land used for agriculture on plains and plateaus is in Western Province, much of this land is used at very low intensity (see Section 1.2).
- Provinces where a high proportion of land used for agriculture is floodplain are East Sepik (22%), Central (22%), Oro (16%), Gulf (16%) and Sandaun (14%).

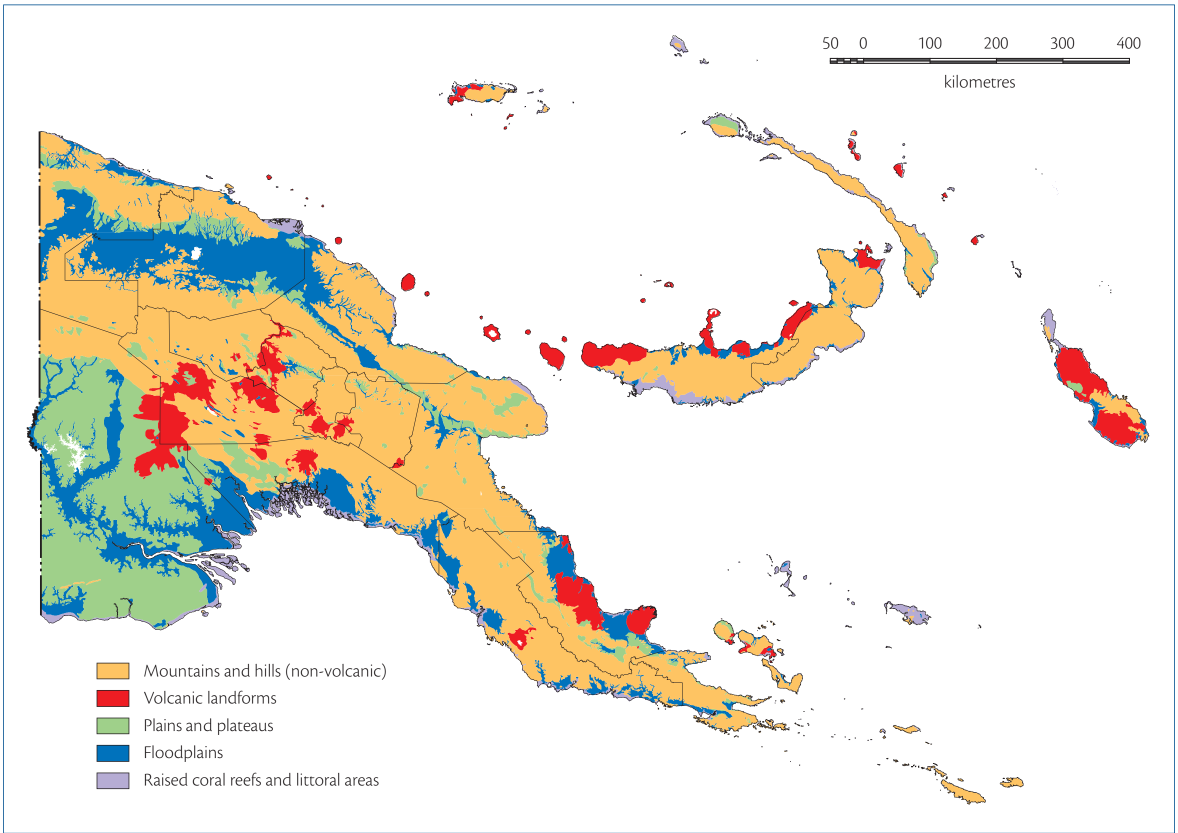

Figure 1.10.1 The five basic landforms of the PNG landscape. Sources: McAlpine and Quigley (c. 1995); PNGRIS.

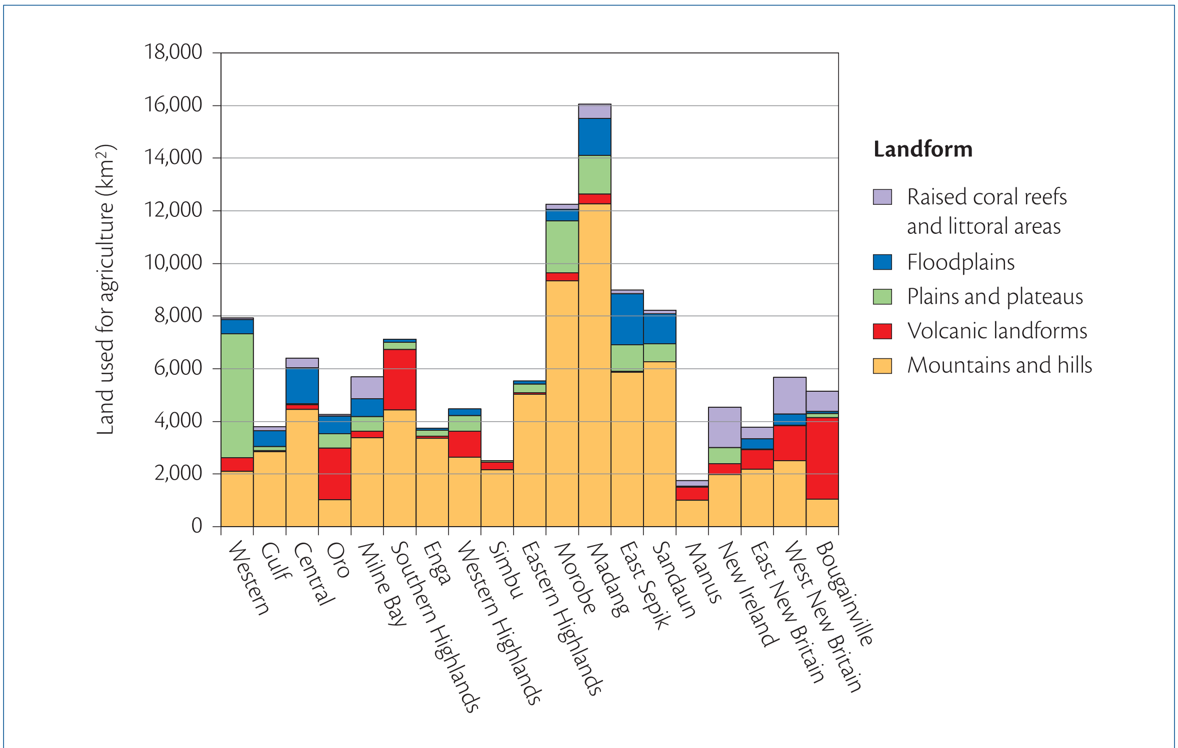

Figure 1.10.2 Land area used for agriculture by landform and province. Sources: McAlpine and Quigley (c. 1995); PNGRIS.

- Coastal landforms used for agriculture are most important in the Islands Region and in Milne Bay Province.
- Approximately half of the population of PNG live on mountains and hills; 17% live on volcanic landforms; 13% on plains and plateaus; and 9% on floodplains. Raised coral reefs and littoral areas – the landform that makes up the smallest area of PNG (only 4%) – support 11% of the population (Table 1.10.1, Figure 1.10.3, Table A1.10.3).
- PNG landforms with the highest population densities on land used for agriculture are raised coral reefs and littoral areas (70 persons/km^2) (Table 1.10.1; see also Table 1.3.1). Population densities on volcanic landforms average 50 persons/km^2 and on plains and plateaus are around 40 persons/km^2. Population densities are lowest on mountains and hills.

Altitude

In PNG, people live and practise agriculture from sea level to around 2800 m above sea level. Above 2800 m, people maintain *Pandanus* orchards and hunt, but they do not cultivate land or maintain settlements. Because PNG is located close to the equator, there is little variation in temperature in most places from month to month during the year (see Table 1.13.1). However, average temperature declines with increasing height above sea level at a rate of 5 °C for every 1000 m of altitude (see Section 1.7), so altitude is an alternative measure for temperature in PNG.

Temperature is a critical determinant of plant growth (see Section 1.13). It also determines the survival range of some insect pests, for example, the *Anopheles* mosquito that transmits malaria. There is evidence that average temperatures are slowly increasing in PNG as a result of climate change (see Section 1.8).

Six altitude classes from PNGRIS, and the maximum and minimum temperatures associated with them, are used here:

- Lowlands (sea level to 600 m), 32–30 °C to 23–19 °C.
- Intermediate (600–1200 m), 30–27 °C to 19–16 °C.
- Highlands (1200–1800 m), 27–23 °C to 16–12 °C.
- High altitude (1800–2400 m), 23–19 °C to 12–9 °C.
- Very high altitude (2400–2800 m), 19–16 °C to 9–7 °C.
- Uninhabited (>2800 m), <16 °C to <7 °C.

These altitude/temperature classes are used because of the crops that grow in them (see Figure 1.13.3). Some crops only grow well up to around 600 m, for example, Polynesian chestnut, *pao* nut and *kangkong*, so 600 m is a convenient place to separate 'lowlands' from the 'intermediate' class. Many tree crops in PNG, such as coconut, betel nut, *tulip* and breadfruit, grow to about 1000–1200 m above sea level, so 1200 m is used to separate the intermediate class from the 'highlands'. Many food and cash crops do not grow well above 1800–2000 m, so 1800 m is a convenient break between the highlands and 'high altitude' classes. Above 2800 m there is no permanent settlement or agriculture. This class is 'uninhabited'.

The following summarise the main points about altitude and agriculture, and altitude and population in PNG:

- Two-thirds of PNG's total land area lies below 600 m altitude and falls into the lowlands environment. The intermediate altitude class is 15% of the total land area and the highlands altitude class 9%. Less than 10% of the total land area is above 1800 m and only 2.5% is above 2800 m (Table 1.10.2, Figure 1.10.4, Table A1.10.4). Above 2200 m, temperatures may fall below freezing on cloud-free nights (see Sections 1.6 and 1.7). The highest point in PNG is Mt Wilhelm (4509 m), on the border of Western Highlands, Simbu and Madang provinces.
- The greatest proportion of land used for agriculture lies between sea level and 600 m (62%) (Figure 1.10.5, Table A1.10.5). The lowest proportion of land used for agriculture is in the very high altitude class, 2400–2800 m (1.4%).

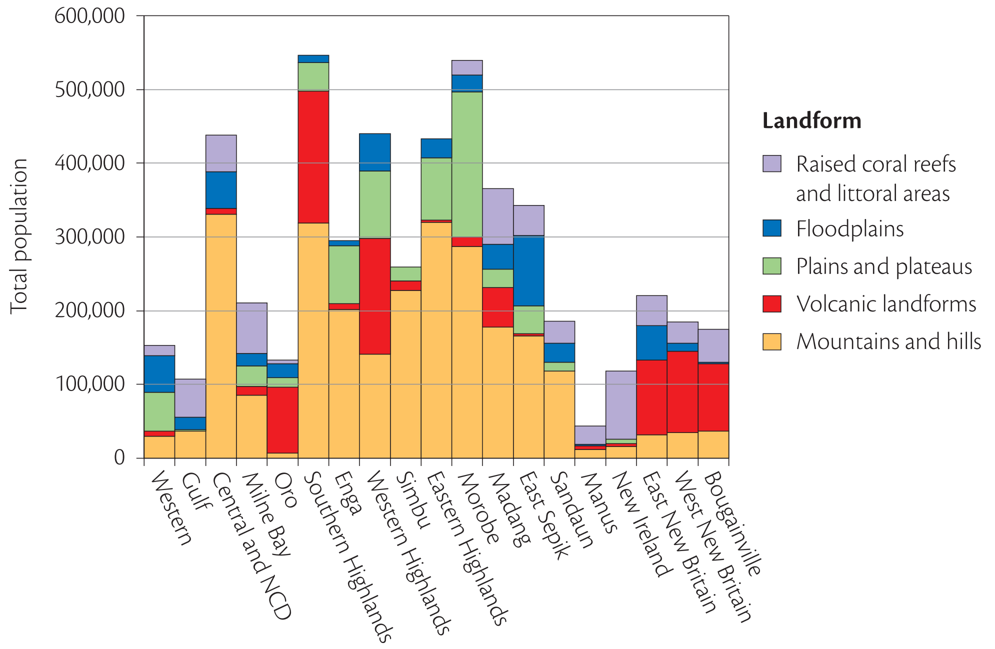

Figure 1.10.3 Total population (including urban and rural non-village populations) by landform and province. Sources: McAlpine and Quigley (c. 1995); NSO (2002); PNGRIS.

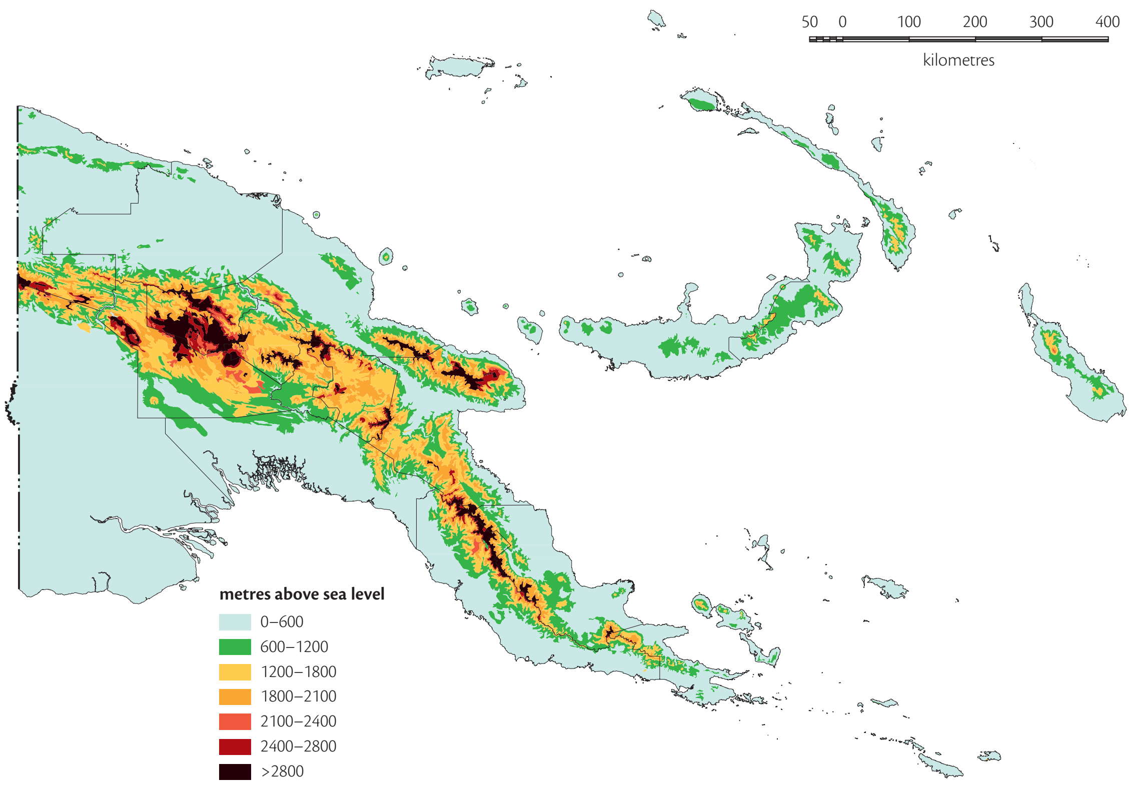

Figure 1.10.4 Altitude classes of the PNG landscape. Sources: McAlpine and Quigley (c. 1995); PNGRIS.

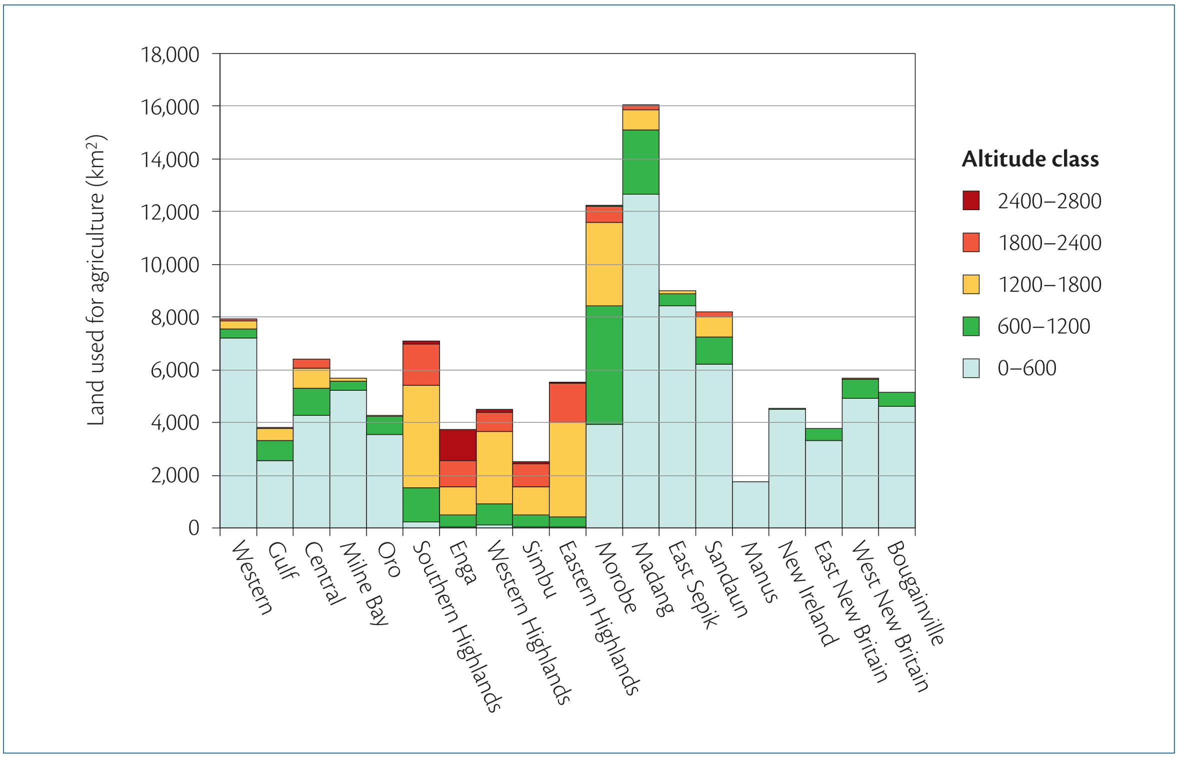

Figure 1.10.5 Land area used for agriculture by altitude class and province.
Sources: McAlpine and Quigley (c. 1995); PNGRIS.

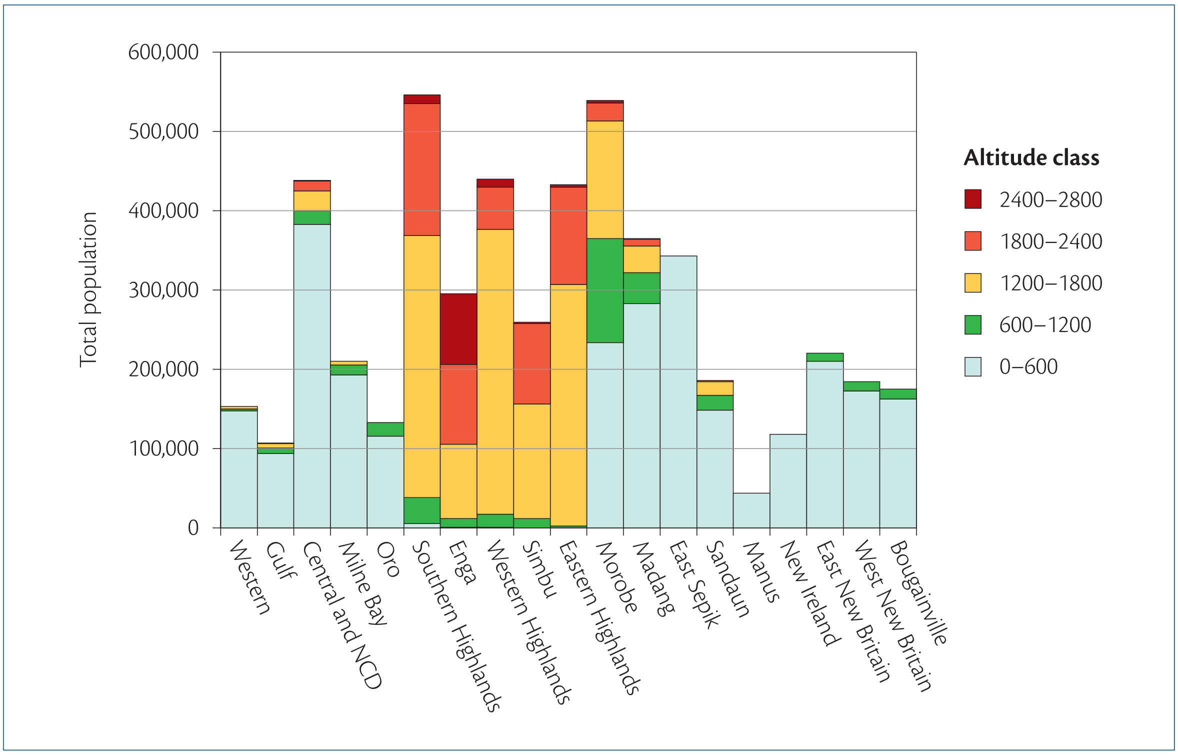

Figure 1.10.6 Total population (including urban and rural non-village populations) by altitude class and province.
Sources: McAlpine and Quigley (c. 1995); NSO (2002); PNGRIS.

- Only in the Highlands Region is agriculture significant above 2400 m, with Enga Province having the highest proportion of land used for agriculture in the 2400–2800 m altitude class (32%).
- In the 1200–1800 m altitude class, the proportion of land used for agriculture, at 43%, is greater than for any other altitude class (Table 1.10.2). This class includes all of the main highland valleys.
- Half of all people in PNG live below 600 m and 42% live above 1200 m (Table 1.10.2).
- There are two altitude classes where fewer people live. These are 600–1200 m and 2400–2800 m. These areas are generally characterised by steep land, very high rainfall and high levels of cloud cover.
- People live above 2400 m in eight provinces, but only in Enga Province do a significant number (89 000) live in the very high altitude class (Figure 1.10.6, Table A1.10.6). Eastern Highlands is the only province in PNG in which no people are recorded living below 600 m.
- A disproportionate number of people, in relation to land area occupied, live between 1200 m and 1800 m (where about 28% of the total population live on 9% of the total land area) and between 1800 m and 2800 m (where about 14% of the total population occupy 7% of the total land area) (Table 1.10.2).
- Population densities between 1200 m and 2800 m are two to four times higher than in the lowlands and intermediate altitude classes.

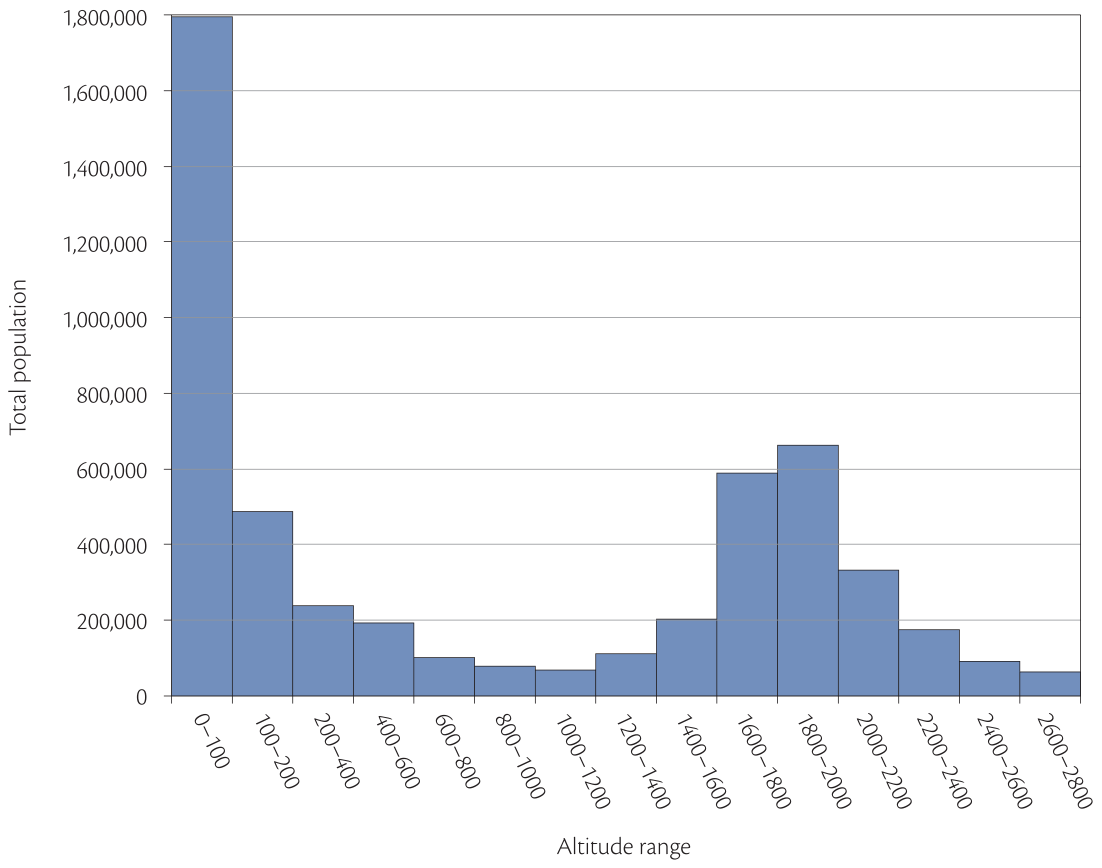

Figure 1.10.7 Total population (including urban and rural non-village populations) by altitude range.
Sources: NSO (2002); digital 1:250 000 topographic map; PNGRIS.

Table 1.10.1 Total land area, land used for agriculture, rural population, and rural population density, by landform

Landform	Total land area		Land used for agriculture		Rural population	Proportion of rural population (%)	Land used for agriculture as a proportion of total land area (%)	Rural population density on land used for agriculture (persons/km²)
	(km²)	(%)	(km²)	(%)				
Mountains and hills	238,028	51.8	73,862	62.7	2,081,808	49.7	31.0	28
Volcanic landforms	36,734	8.0	13,542	11.5	693,711	16.5	36.9	51
Plains and plateaus	85,933	18.7	13,399	11.4	553,461	13.2	15.6	41
Floodplains	81,556	17.7	10,277	8.7	391,000	9.3	12.6	38
Raised coral reefs and littoral areas	17,603	3.8	6,778	5.8	472,580	11.3	38.5	70
Papua New Guinea	459,854	100.0	117,858	100.0	4,192,561	100.0	25.6	36

Sources: McAlpine and Quigley (c. 1995); NSO (2002); PNGRIS.

Table 1.10.2 Total land area, land used for agriculture, total population (including urban and rural non-village populations), and total population density, by altitude class

Altitude class (metres above sea level)	Total land area		Land used for agriculture		Total population	Proportion of total population (%)	Land used for agriculture as a proportion of total land area (%)	Total population density on land used for agriculture (persons/km²)
	(km²)	(%)	(km²)	(%)				
0–600	303,844	66.1	73,531	62.4	2,654,521	51.1	24.2	36
600–1200	69,505	15.1	16,766	14.2	354,262	6.8	24.1	21
1200–1800	43,416	9.4	18,844	16.0	1,471,042	28.3	43.4	78
1800–2400	25,359	5.5	7,126	6.0	590,928	11.4	28.1	83
2400–2800	6,275	1.4	1,591	1.4	120,033	2.3	25.4	66
>2800	11,455	2.5	0	0.0	0	0.0	0.0	0
Papua New Guinea	459,854	100.0	117,858	100.0	5,190,786	100.0	25.6	44

Sources: McAlpine and Quigley (c. 1995); NSO (2002); PNGRIS.

The altitude data above was extracted from PNGRIS (see Section 1.15) where resource mapping units (RMUs) are allocated an altitude class and the census units (CUs) located in all the RMUs are summed by altitude class. Another means of deriving information about population and altitude is to use geographic information system software to join a digital map of CUs to a map of contour lines and to give the CUs the altitude of the nearest contour line.

An analysis of population distribution by this second method is illustrated in Figure 1.10.7 and Table A1.10.7. It shows the largest concentration of people, both rural and urban, is from sea level to 100 m altitude (35% of the total population). The other altitude zone where there is a high concentration of people is in the valleys and basins of the highlands over the altitude range of 1600–2000 m (24%). Note that these two techniques give a somewhat different picture of the distribution of the population by altitude class, especially in the highlands. However, the overall trends are the same using both methods.

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1.11 Agricultural environments

Agriculture involves the production, from plants and animals, of food and other products useful to people. Environmental conditions such as temperature, rainfall, rainfall seasonality, flooding, soil fertility, soil structure and slope all influence agricultural production. Different combinations of environmental conditions will favour or constrain production from particular plants and animals.

An understanding of environments and the opportunities and limitations they present to agriculture is important. If we know what combinations of environmental conditions best suit particularly successful economic plants or agricultural practices, we can look for other places that might be suitable for the introduction of those plants or practices. Knowledge of environmental conditions can be used to assess where investment in agricultural research will give the greatest returns or will benefit the largest possible number of people.

A powerful way to examine agricultural environments is to produce a map of them (for example, Figure 1.11.1). What combinations of environmental conditions are included or excluded when a map of agricultural environments is drawn depends on the purpose for creating the map. The same basic information about the environment can be combined in many different ways for different purposes.

The construction of an agricultural environment map also depends on the availability and reliability of information about individual environmental conditions. For example, rainfall data may be of a high quality, but information about soils poor. In such a case, it would be better not to use that soils information, or to reduce its influence, in the creation of a map of agricultural environments. Temperature, rainfall and inundation are environmental attributes that are reasonably consistent over large areas. Characteristics like soil fertility, soil structure and slope often vary greatly over shorter distances and so are more difficult to use.

An agricultural environment map of PNG

In this section, three environmental conditions important for PNG agriculture are combined to create a map of agricultural environments (Figure 1.11.1). This type of map is particularly suitable for research planning. The conditions are:

- Altitude (as an alternative for temperature).
- Soil water deficit (the likelihood of drought, based on a soil water balance from 54 PNG climate stations for a 15-year period).
- Inundation (the degree of flooding).

Information about these conditions is taken from the Papua New Guinea Resource Information System (PNGRIS) (see Section 1.15).

Altitude/temperature

Temperature has a significant influence on crop production. In PNG, temperature is most influenced by altitude (see Sections 1.7 and 1.10).

For the purpose of analysis here, the six altitude classes described in Section 1.10 have been reduced to the following four classes:

- Lowlands (sea level to 600 m).
- Intermediate (600–1200 m).
- Highlands (1200–1800 m).
- High altitude (1800–2800 m).

Soil water deficit/rainfall deficit

A lack of water in the soil can limit production of most common agricultural food plants. In PNG, too much water in the soil frequently limits agricultural production rather than not enough water. However, it is important to note that soils do dry out for a period of weeks in PNG. Dry periods occur in some places every year and in most places on average every 10–15 years. A measure of when low soil moisture conditions limit plant growth is 'soil water deficit' (see Section 1.5).

The five patterns of soil water balance described in Section 1.5 have been collapsed into three classes for analysis here:

- Strong soil water deficit (a regular and severe soil water deficit – plant growth is limited by soil moisture conditions for 5–7 months every year).
- Moderate soil water deficit (infrequent deficit – plant growth is limited by soil moisture conditions for 2–4 months every year).
- No soil water deficit (places where sufficient rain falls in all months of the year in most years – plant growth is not limited by soil moisture conditions or is limited for only one month every year).

Note that these classes of soil water deficit (5–7 months, 2–4 months and 0–1 dry month) are based on average rainfall, and actual soil moisture levels vary from year to year. Soil water deficits also vary with the type of soil, although this is less important than rainfall. The consequences of soil water deficits vary from crop to crop but, in general, they determine when crops grow during the year: the three classes correspond to growing periods of 5–7 months, 8–10 months and 11–12 months respectively.

Nearly half of the country experiences moderate soil water deficit. However, 43% of the land has no significant deficit and only 8% has a strong deficit (Figures 1.11.2, 1.5.5). Strong water deficit occurs only in the lowlands. In the other three inhabited altitude classes, only 'moderate soil water deficit' or 'no soil water deficit' occur (Table 1.11.1).

Inundation (flooding)

Inundation occurs when the soil surface is covered with water, or flooded. Flooding is a severe limitation to most forms of agriculture. Inundation is a reliable indicator of where most plants are unlikely to grow well. A notable exception is sago; inundated locations are often places where sago is an important food.

The nine classes of inundation described in PNGRIS are here collapsed into two classes:

- No inundation (PNGRIS Class 0: land is never flooded).
- Inundation (PNGRIS Classes 1–8: land is flooded briefly, seasonally, or permanently flooded, as in a swamp).

In PNG, 33% of the total land area is inundated in some way, which leaves 67% that is not inundated. Almost all inundated land is in the lowlands altitude class. A number of very small areas of inundation occur in the highlands altitude class, but they have been excluded in order to simplify this analysis.

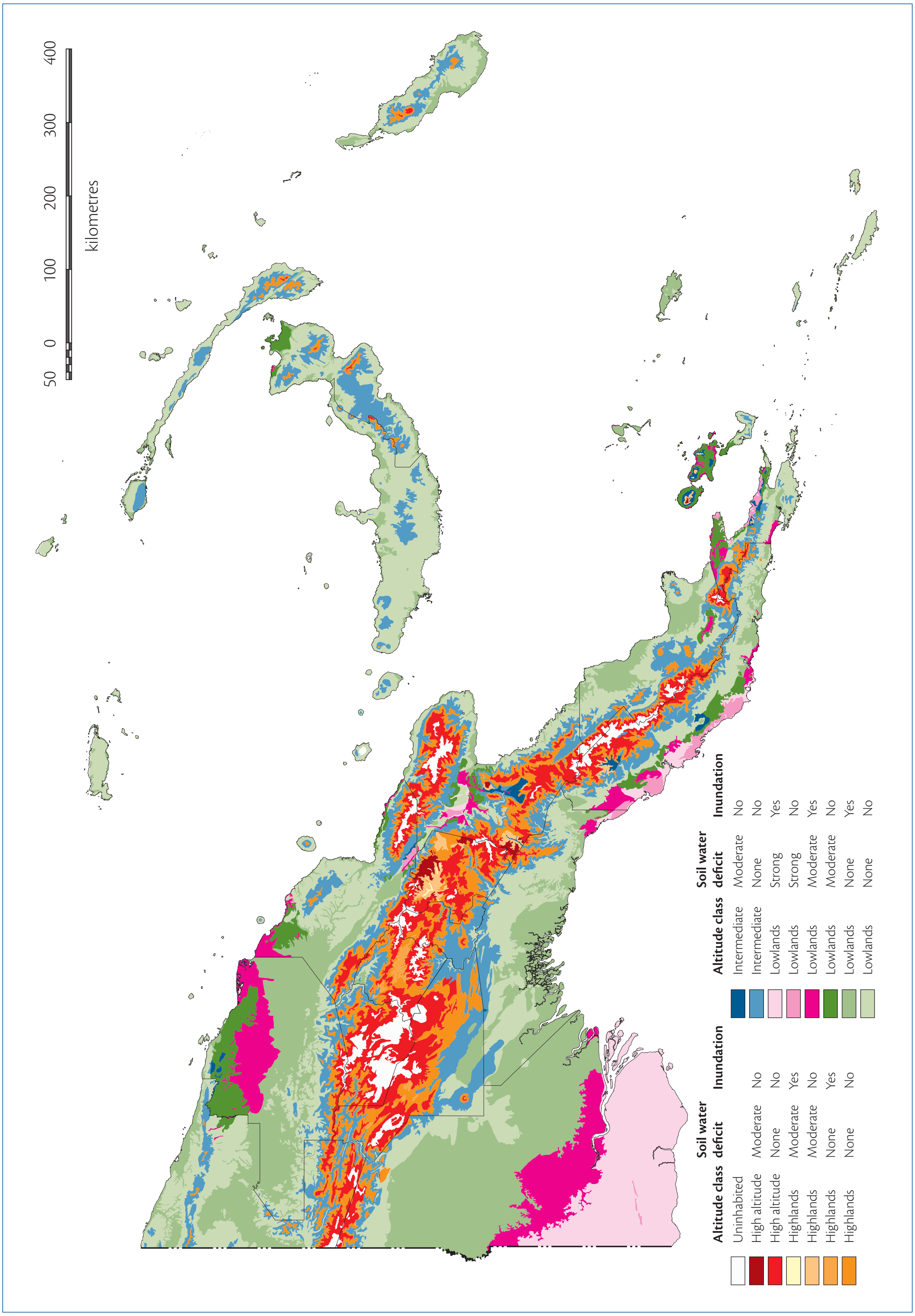

Figure 1.11.1 Agricultural environments based on altitude (temperature), soil water deficit (rainfall deficit) and inundation classes. Source: PNGRIS.

The three conditions combined into agricultural environments

When all possible combinations of the environmental conditions of altitude/temperature, soil water deficit and inundation described in this section are combined and mapped, the outcome is 14 agricultural environments, plus the very high altitude environment that is presently uninhabited and not used for agriculture. Within each environment, there are big differences in soil fertility and slope that cannot be shown at the scale used here. However, these 14 broad classes can be used to identify where a particular crop might grow best or where an agricultural practice that has proved successful elsewhere might be suitable. An example is the practice of planting casuarina trees in fallow gardens. Within each class, further work in the field can identify local land that is not too steep and is reasonably fertile.

The distribution of PNG's population by agricultural environment is of interest for a number of reasons. It provides an indication of the numbers of people who would benefit from research or other activities within a given environment. It also gives insights into what sort of environments have been favoured by Papua New Guinean agriculturalists over long periods of time.

Almost half of all rural Papua New Guineans live in lowlands environments. A further 27% of the rural population live in highlands environments and 17% in high altitude environments, leaving only 7% in intermediate altitude environments (Table 1.11.1).

Of those who live in lowlands environments, around 70% favour environments which are not inundated and which do not have a strong soil water deficit. Across the country, inundation is associated with low population densities. In highlands environments population densities are higher where there is a moderate soil water deficit and no flooding.

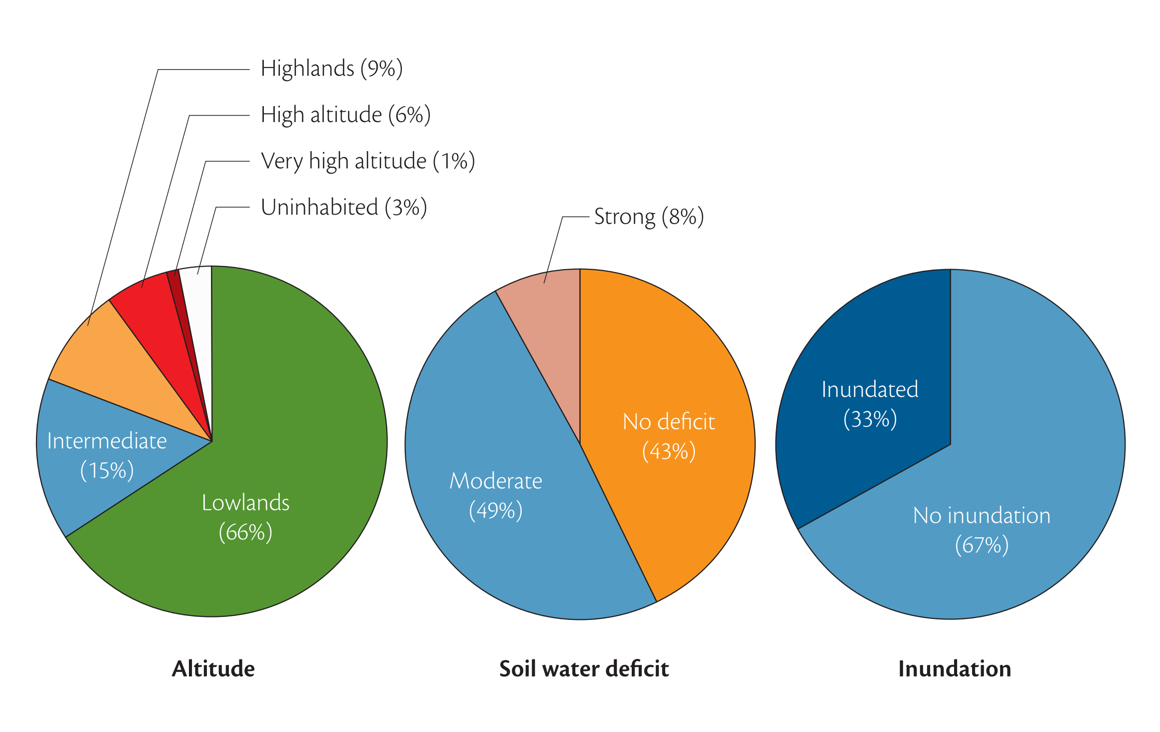

Figure 1.11.2 Proportion of the total land area by altitude (temperature), soil water deficit (rainfall deficit) and inundation classes. Source: PNGRIS.

Table 1.11.1 Total land area, rural population and rural population density, by agricultural environment

Agricultural environment	Total land area (km²)	(%)	Rural population	Proportion of rural population (%)	Proportion of population in altitude class (%)	Rural population density on total land area[a] (persons/km²)
Lowlands–Strong soil water deficit–Inundation	31,200	6.8	36,675	0.9	1.8	1.2
Lowlands–Strong soil water deficit–No inundation	3,828	0.8	126,466	3.0	6.2	33.0
Lowlands–Moderate soil water deficit–Inundation	61,744	13.4	218,048	5.2	10.6	3.5
Lowlands–Moderate soil water deficit–No inundation	67,066	14.6	893,196	21.3	43.5	13.3
Lowlands–No soil water deficit–Inundation	56,118	12.2	256,559	6.1	12.5	4.6
Lowlands–No soil water deficit–No inundation	83,889	18.2	523,523	12.5	25.5	6.2
Lowlands altitude class (sea level to 600 m) total	303,844	66.1	2,054,466	49.0	100.0	6.8
Intermediate–Moderate soil water deficit–No inundation	25,821	5.6	137,770	3.3	49.6	5.3
Intermediate–No soil water deficit–No inundation	43,684	9.5	140,122	3.3	50.4	3.2
Intermediate altitude class (600–1200 m) total	69,505	15.1	277,893	6.6	100.0	4.0
Highlands–Moderate soil water deficit–Inundation	741	0.2	72,453	1.7	6.4	97.8
Highlands–Moderate soil water deficit–No inundation	19,398	4.2	702,453	16.8	62.3	36.2
Highlands–No soil water deficit–Inundation	114	0.0	544	0.0	0.0	4.8
Highlands–No soil water deficit–No inundation	23,163	5.0	352,951	8.4	31.3	15.2
Highlands altitude class (1200–1800 m) total	43,416	9.4	1,128,400	26.9	100.0	26.0
High altitude–Moderate deficit–No inundation	14,091	3.1	303,956	7.2	41.5	21.6
High altitude–No soil water deficit–No inundation	17,543	3.8	427,845	10.2	58.5	24.4
High altitude class (1800–2800 m) total	31,634	6.9	731,802	17.5	100.0	23.1
Uninhabited altitude class–Moderate deficit–No inundation	11,455	2.5	0	0.0	0.0	0
Uninhabited altitude class (>2800 m) total	11,455	2.5	0	0.0	0.0	0.0
Papua New Guinea	459,854	100.0	4,192,561	100.0		9.1

[a] This is rural population density on the *total* land area. Do not confuse it with the total population density on land used for agriculture – see Table 1.10.2 and Sections 1.2 and 1.3.

Sources: NSO (2002); PNGRIS.

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1.12 Land quality

Measuring land quality

Land quality can be assessed in a number of ways. It is measured here as 'resource potential', or the ability of the land to grow particular crops at their optimum production over a long period of time. Resource potential is determined by identifying conditions that will prevent optimum plant growth. These are known as 'constraints' and include, for example, infertile soils or soils that will lose fertility quickly, too much or too little water in the soil, steep slopes that will erode if cultivated, and low temperatures. Each constraint is given a score depending on how critical it is to plant growth over the long term, relative to all the other constraints. The constraints are added together and areas of land are examined to see how well they score against all the constraints.

People commonly overcome some constraints by modifying the environment. So swampy land is drained to lower soil water levels (see Sections 1.5, 1.11 and 3.12), physical barriers are constructed across slopes to slow or prevent soil erosion (see Section 3.9), and green manures are used to maintain soil fertility over many cropping cycles (see Section 3.11). The type of modification that is used often depends on the crop species being grown. For example, taro is constrained less by high soil water levels than sweet potato, and so drainage is less important if taro is to be grown than if sweet potato is the chosen crop.

Methods of classifying land according to its quality depend on the accuracy of the information available. The resource mapping units (RMUs) of PNGRIS provide a convenient unit of analysis and contain information on natural resources that is reasonably accurate at provincial and national scales (see Section 1.15). Resource potential, or land quality, is usually estimated relative to a particular crop or land use. The constraints to optimum growth are estimated for particular species and the outcome applies only to that species, or to other similar plants.

The assessment of land quality presented here (see Figure 1.12.1) is based on the potential of land in PNG to grow sweet potato. It was carried out using the following information:

- Altitude (as an alternative for temperature) (from PNGRIS).
- Inundation or flooding (from PNGRIS).
- Slope (from PNGRIS).
- Soil type (from PNGRIS).
- Annual rainfall (from the ANU's Centre for Resource and Environmental Studies rainfall surface for PNG; see Figure 1.5.2).
- Light (measured as cloud cover by the Australian Geological Survey from the United States' National Oceanic and Atmospheric Administration satellite imagery data).

Sweet potato was chosen because it is grown in almost all inhabited parts of PNG, it is the staple food for more than 60% of the population and a lot is known

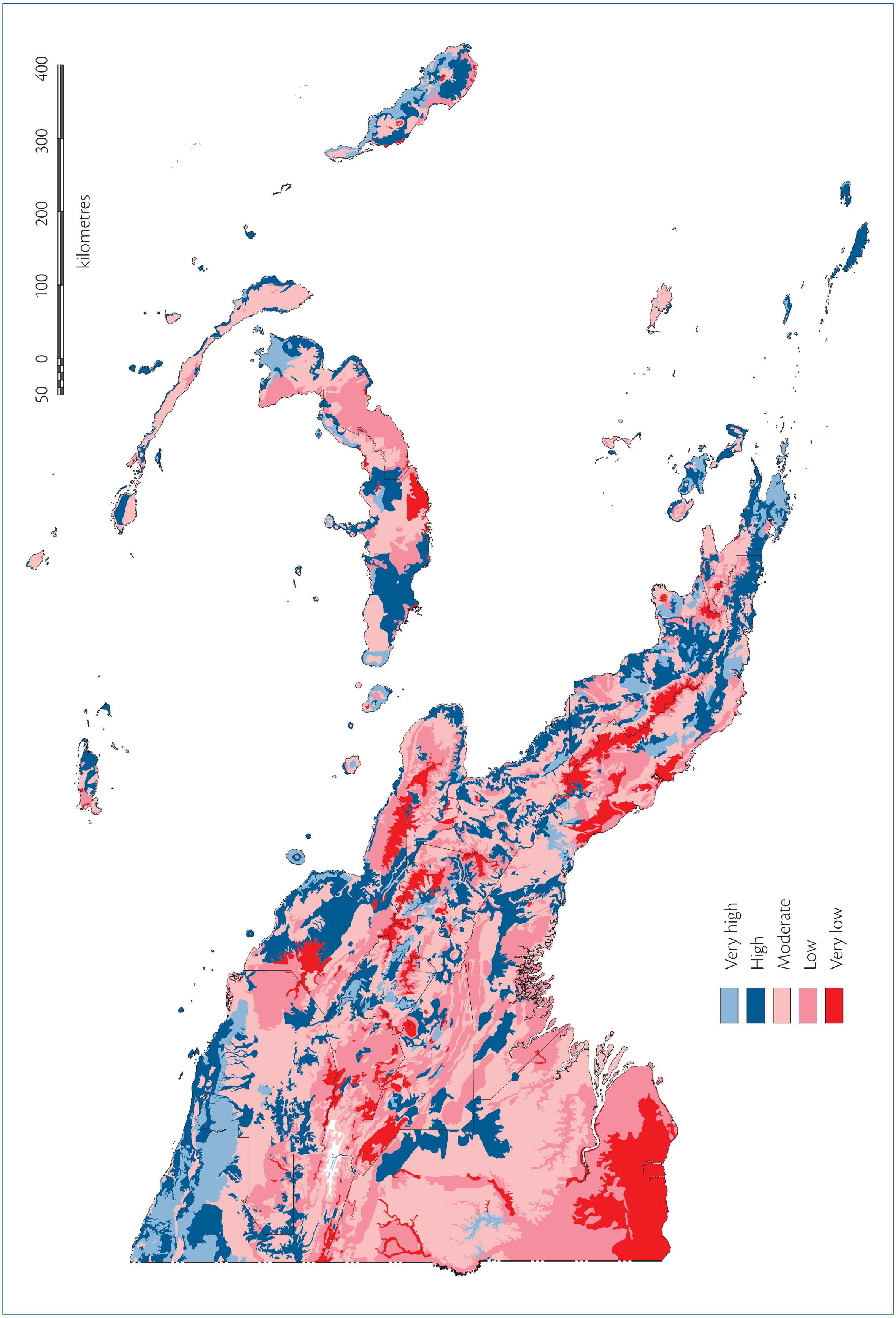

Figure 1.12.1 Land quality. Source: PNGRIS.

about constraints to its optimum growth. In the analysis presented here, modifications to the environment, such as draining or composting, are *not* taken into account. For an example of an analysis where environmental modifications are taken into account, see Hanson, Bourke, Allen and McCarthy (2001).

Land quality in PNG

Using the above measures to determine the potential of land to grow sweet potato, the following points can be made about land quality in PNG:

- It is predominantly of low quality. More than 70% of the total land area is of low or very low quality (it must be remembered, however, that only 25% of the total land area of PNG is used for agriculture (see Section 1.2), and much of the poorest quality land is not occupied by people); 20% of the total land area is of moderate potential and only 7% is of high or very high potential (Table 1.12.1, Figure 1.12.2, Table A1.12.1).
- Most of the people in PNG produce food from land of moderate to low quality. Up to 80% of the population occupies land of moderate or lower potential. Only 20% occupy high or very high quality land (Table 1.12.1).
- High quality land is associated with volcanic landforms or with land covered with volcanic tephra (fine material that has fallen on the land following a volcanic eruption). The largest area of high quality land that is presently unoccupied surrounds active and dangerous volcanoes that are known to have erupted and killed people in the relatively recent past.
- Of the estimated 983 000 people who occupy high and very high quality land, almost 30% live in either East New Britain Province or Western Highlands Province. A further 12% live in East Sepik Province and 10% live in Sandaun Province (Figure 1.12.3, Table A1.12.2).
- Of the estimated 2.8 million people who occupy very low or low quality land, 24% live in Morobe Province or Southern Highlands Province and a further 18% in Eastern Highlands or Enga provinces.
- People are not evenly distributed over poor and good quality land, but are concentrated on better quality land. Average population densities on high and very high quality land are between four and eight times those on poor quality land (Table 1.12.1, Figure 1.12.4).

Over the long term people can produce food from poor quality land either because they use it at low intensities (land may be used only once every 20 to 30 years) (see Section 1.2) or because they use special techniques to overcome constraints to crop growth, such as draining a swamp or using green manure to maintain soil fertility.

Table 1.12.1 Total land area, rural population and rural population density, by land quality (the potential of the land to grow sweet potato)

Land quality	Total land area (km²)	Total land area (%)	Rural population	Proportion of rural population (%)	Rural population density (persons/km²)
Very low	85,270	18.5	456,989	10.9	5
Low	251,563	54.7	1,773,453	42.3	7
Moderate	92,121	20.0	1,123,606	26.8	12
High	20,532	4.5	419,256	10.0	20
Very high	10,368	2.3	419,256	10.0	40
Total	459,854	100.0	4,192,561	100.0	9

Sources: NSO (2002); PNGRIS; land quality calculated by Luke Hanson.

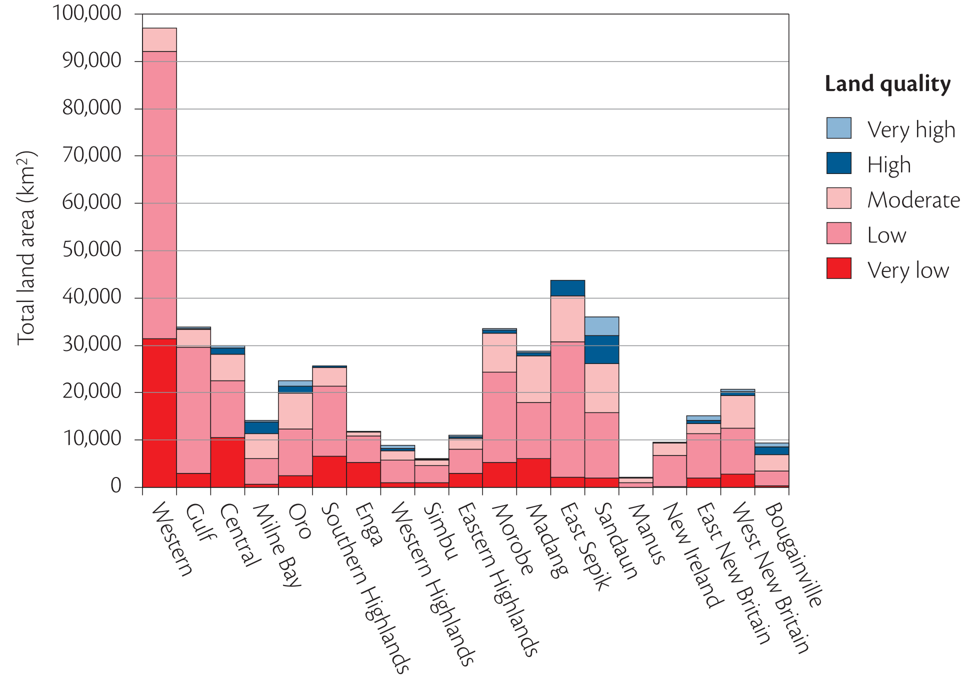

Figure 1.12.2 Total land area by land quality and province. Source: PNGRIS.

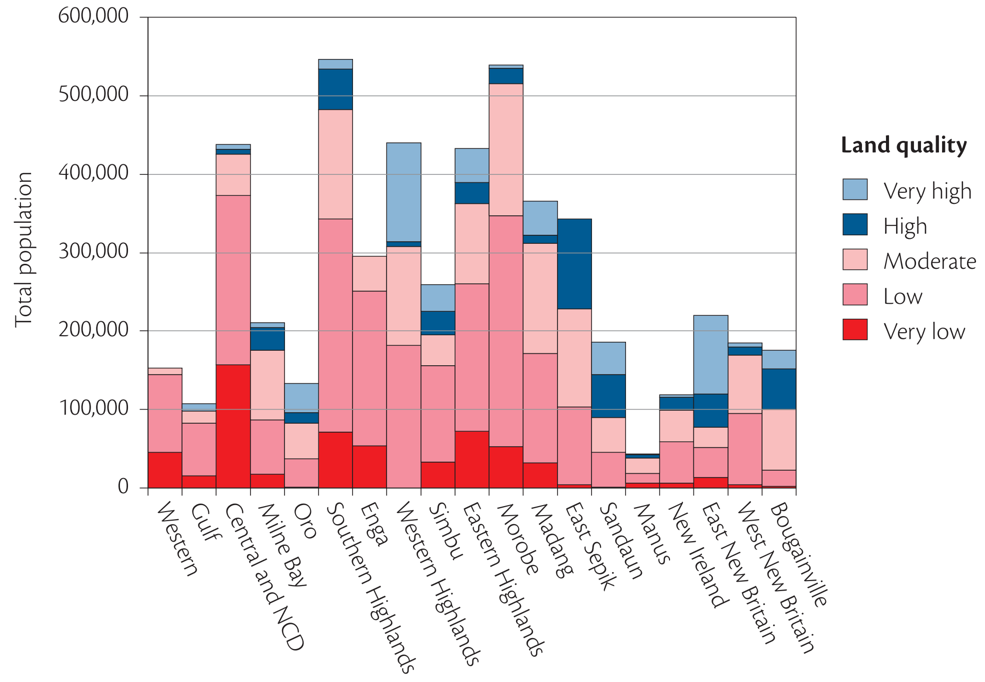

Figure 1.12.3 Total population (including urban and rural non-village populations) by land quality and province. Sources: NSO (2002); PNGRIS.

The results of land quality analyses always require some qualification. The results of the analysis here are no different. This analysis of land quality classifies high altitude areas as low quality, for reasons associated with the boundaries of PNGRIS RMUs and the altitude classes used in PNGRIS. Hence highlands provinces are almost certainly over-represented in the classes of lower land quality. Although sweet potato is known to produce relatively slowly at higher altitudes (6–8 months to main harvest compared to 3–5 months at lower altitudes), high altitude land quality is not as poor as this analysis suggests. This analysis also produces other results that are difficult to interpret, such as the large areas of high quality land in Sandaun Province. These outcomes may result from errors in PNGRIS data for this province.

These results emphasise the need to interpret the findings of land quality analyses in the light of other knowledge. Findings should never be accepted unquestioningly. That said, the broad overall pattern of land quality in PNG presented here will not change greatly if another crop is substituted for sweet potato, or other adjustments are made. The greatest changes will occur if tree crops, banana or sago are used in the analysis. An analysis of the suitability of land for producing cocoa and coconuts was done by Hanson et al. (1998).

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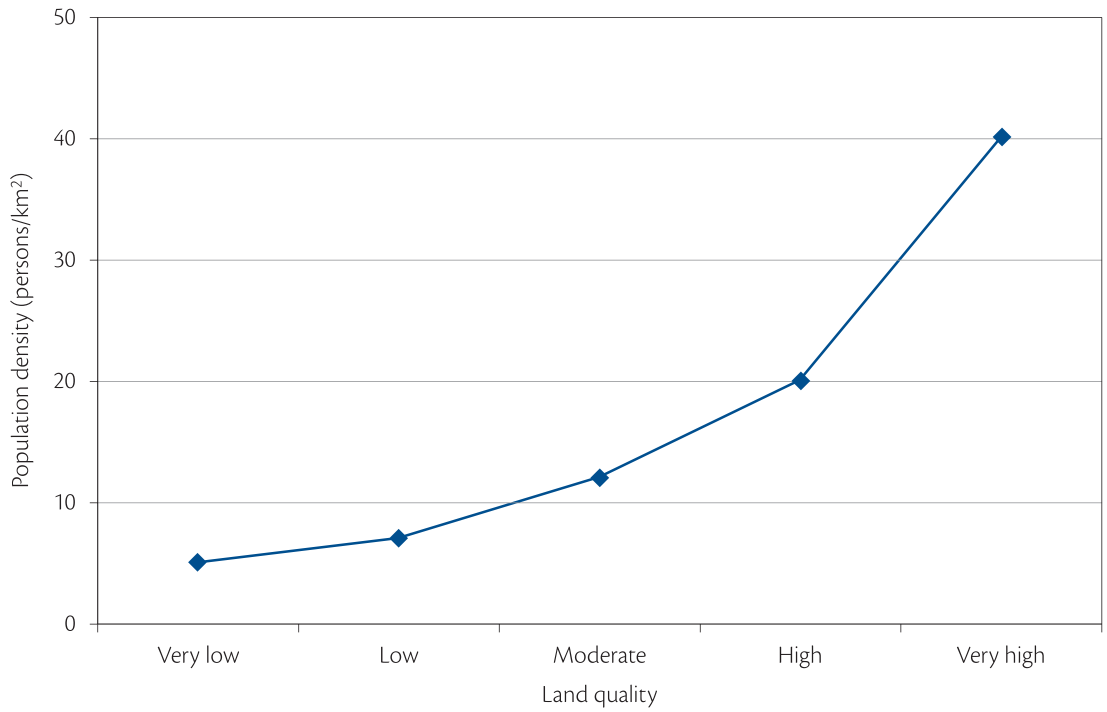

Figure 1.12.4 Association between land quality and population density. Sources: NSO (2002); PNGRIS.

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1.13 Crops, people and the environment

Planted crops are the basis for agriculture in PNG. The natural physical environment influences which crops can be grown in a particular location, how well a crop performs, and other matters such as when flowering occurs, the time from flowering to fruit maturity, and fruit flavour. People can influence the relationship between the physical environment and a crop to some degree, either by selecting the environment for planting a crop or by modifying the environment. An example of people selecting the environment would be planting a crop that requires high soil fertility in a part of a food garden where the soil is deeper and more fertile. Examples of people modifying the environment include transferring organic material into a garden (composting) or digging drains to reduce the amount of water in the soil.

This section examines how aspects of the physical environment affect plant growth and yield and how people influence this in PNG. The information is organised by main environmental factors. Sometimes more than one environmental factor is important in determining how well crops grow, and sometimes people's practices can have multiple effects.

An example of a practice having multiple benefits is the use of mixed species plantings in food gardens, a technique widely used in PNG. This is a very efficient practice and generally results in higher total yields and reduced labour inputs for the same area, compared with planting a single species (monocropping). The benefits from mixed species cropping include more efficient use of available sunlight, with shade-tolerant crops planted under sun-loving species. An example is Chinese taro planted under banana.

Another benefit of mixed species planting is the more efficient use of soil nutrients and soil moisture, with quick-growing species using some nutrients before they are needed by slower-growing species, and before they can be leached from the soil. Different crops also have different needs for soil nutrients, so planting a mix of species can mean that the species are not competing for the same nutrients. For example, green vegetables have a high demand for nitrogen, whereas root crops and banana have a high demand for potassium, a nutrient that is less important for most leafy greens. Roots of the different species also use nutrients from different soil depths. As well as the total crop yield being greater from mixed plantings, the labour inputs are often less because of a reduced need for weeding.

Aspects of the physical environment that have the greatest influence on plant growth are rainfall, cloud cover, temperature, daylength, inundation (flooding) and soil fertility. Some of these factors are in turn influenced by others, such as altitude, latitude, slope, landform and underlying rock type. The various attributes outlined here are described in more detail in sections elsewhere: 1.5 (rainfall), 1.7 (temperature, cloudiness and sunshine), 1.9 (soils) and 1.10 (landforms and altitude). Combinations of these factors are discussed in Sections 1.11 (agricultural environments) and 1.12 (land quality).

Rainfall

A number of aspects of rainfall influence plant production, including total annual rainfall, its seasonal distribution, variability between years, extremes (drought or periods of particularly high rainfall) and intensity (millimetres per hour) (see Section 1.5). The optimum annual rainfall for many crops in PNG is 1500 to 3000 mm per year (125 to 250 mm per month). For many crops, a period during the year of 1–3 months where the monthly rainfall is somewhat less (50 to 100 mm) is also a benefit. Crops tend not to grow so well in locations where the total annual rainfall is greater than 4000 mm. Some crops are more tolerant of high rainfall than others. For example, oil palm produces well in locations with an annual rainfall of up to 3500 mm, whereas cocoa does best where the annual rainfall is between 1800 mm and 2600 mm. Sweet potato is vulnerable to high levels of soil moisture, whereas taro is much more tolerant of wetter soil conditions. Despite this, sweet potato is grown in locations where the rainfall is high to very high and people use mounds or drains to reduce soil water levels.

Rainfall seasonality influences crop growth in a number of ways. Some species require a drier period in the year for flowering and fruiting, although many of the crops grown in PNG produce even without a drier period each year. Mango is a good example of a food crop that requires a period of drier weather to induce flowering. Higher rainfall and humidity during the period that mango flowers are forming can allow fungal growth that causes flowers to abort, thereby reducing fruit yield. *Karuka* nut pandanus is another crop where flowering and fruiting is induced by drier weather. In places that experience a regular drier period each year, such as Eastern Highlands Province, fruiting is more regular. However, in the western part of the highlands where the annual rainfall is less seasonal, production of fruit is less regular. The best yields of *karuka* nut follow mild droughts.

In locations where there is regular variation in the seasonal distribution of rainfall, villagers adapted their agricultural systems to avoid interruptions to food supply. Where rainfall is well distributed throughout the year, taro was generally the main staple food in the lowlands. In more seasonal environments, people grew more banana and yam. Where the rainfall distribution was markedly seasonal, the agricultural system was based on a combination of taro, yam and banana, sometimes with sago being used for part of the year. Using a mix of crops with varying times to maturity spread the supply of food more evenly throughout the year. In some strongly seasonal locations, especially on small islands and in Milne Bay Province, foods from trees including breadfruit and Polynesian chestnut

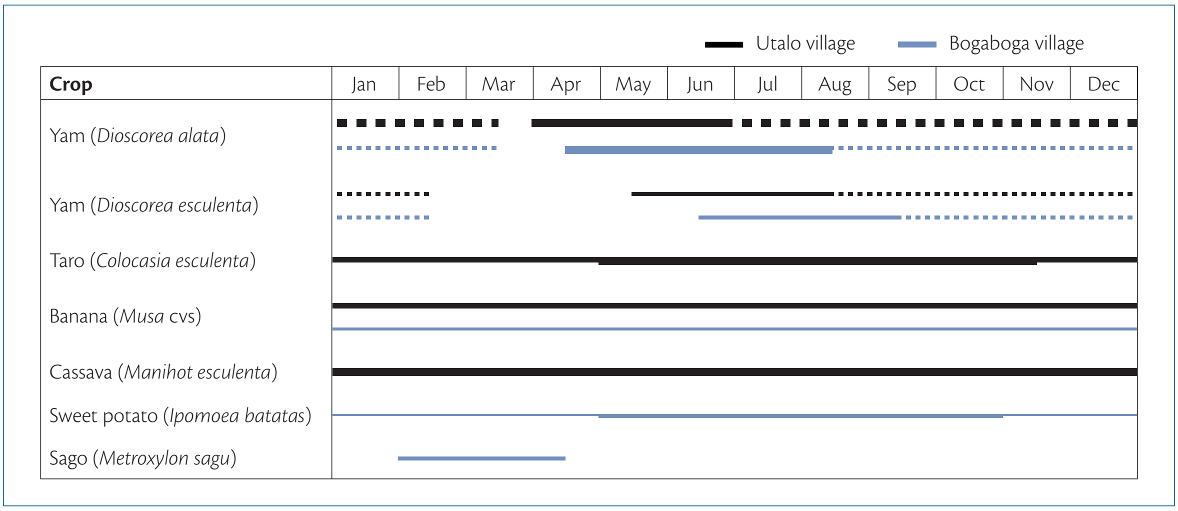

Figure 1.13.1 Food availability at Utalo village, Goodenough Island, and Bogaboga village, Cape Vogel area, Milne Bay Province. **Note:** A solid line indicates availability directly from food gardens. A dashed line indicates availability from storage. The thickness of the bands indicates relative abundance. Source: Mogina (2002:159).

(*aila*) were important when the supply of garden food was low. The availability of foods at two locations in Milne Bay Province is illustrated in Figure 1.13.1. Over the past 130 years, villagers have incorporated sweet potato, cassava, corn and other introduced foods into their agricultural systems. This has allowed greater flexibility in the food production systems and spread the supply of food more evenly throughout the year.

Seasonality of rainfall influences the timing of crop planting. In some locations in PNG, the main food gardens are planted prior to the wetter part of the year, often in about September–October. In the highlands, the mixed vegetable gardens are commonly planted at this period, which results in a greater supply of some foods in the months that follow. Figure 1.13.2 shows when amaranthus, common bean, corn and cucumber are most abundant in a number of highland markets.

A period of lower rainfall is often desirable to break a cycle of disease build-up, and is particularly important in PNG where there is little seasonal change in temperature. Taro blight, a fungal disease, is worst in locations where there is no annual drier period. A number of crops, including watermelon, cucumber and rockmelon, only bear well when planted during drier months, almost certainly because pests and diseases are worse when rainfall is higher.

Drought is an extreme form of rainfall variability. It is difficult for villagers to devise an agricultural system to accommodate an event such as a major drought that occurs infrequently and in an unpredictable manner (see Section 1.6). People have many responses to surviving a drought, including eating plants and parts of plants that are not normally eaten, such as very small tubers, or eating uncultivated ('wild') plants, including ferns, wild yams and *kudzu* tubers. Another strategy is to migrate to locations where the food supply is better. In the modern context, people often buy locally grown or imported food using cash.

People make a number of modifications to the environment to influence soil moisture so that it does not interfere with plant growth. In most of PNG, the main concern is removal of excess water, and the construction of drains is a common technique, especially in sweet potato gardens in the highlands. Crops, especially sweet potato and yam, may also be planted on mounds to allow excess moisture to drain away from the root zone. In the past, where a lack of water for part of a year was the problem, irrigation of taro and other crops was practised, but irrigation is now restricted to a limited number of places, the most important being the Rabaraba area of Milne Bay Province. In Eastern Highlands and Morobe provinces, taro was irrigated using bamboo pipes. At Rabaraba, streams at the top of large alluvial fans are diverted into ditches that allow water to be distributed to areas under cultivation, while other areas are left in fallow, uncultivated and unirrigated (see Section 3.12).

Cloud cover

High levels of cloudiness tend to be associated with high rainfall and less direct sunlight (see Section 1.7). The combination of excessive soil moisture and less direct sunlight results in poorer plant growth for many crops. This is one reason why yields of grain crops, such as rice and corn, are not particularly high in PNG. The highest yields of rice occur where there are a high number of hours of bright sunshine in the day and water supply is plentiful. These conditions occur, for example, in the Murrumbidgee Irrigation Area of New South Wales, Australia.

Yields of sweet potato and other crops tend to be lower on the southern sides of the main mountain ranges, for example, in Southern Highlands Province and mountainous parts of Gulf Province. This is because of both excessively high rainfall and high levels of cloudiness. In mountainous locations where clouds form early in the day and reduce sunlight, human settlement and agriculture is generally absent.

Temperature

Altitude has the greatest influence on temperature in PNG (see Sections 1.7 and 1.10). Above 500 m, there is a regular decline in temperature with increasing altitude. Other factors that have an influence on temperature are geomorphology (landforms; see Section 1.10) and latitude (distance from the equator). Seasonal differences in temperature are very small at locations near the equator, for

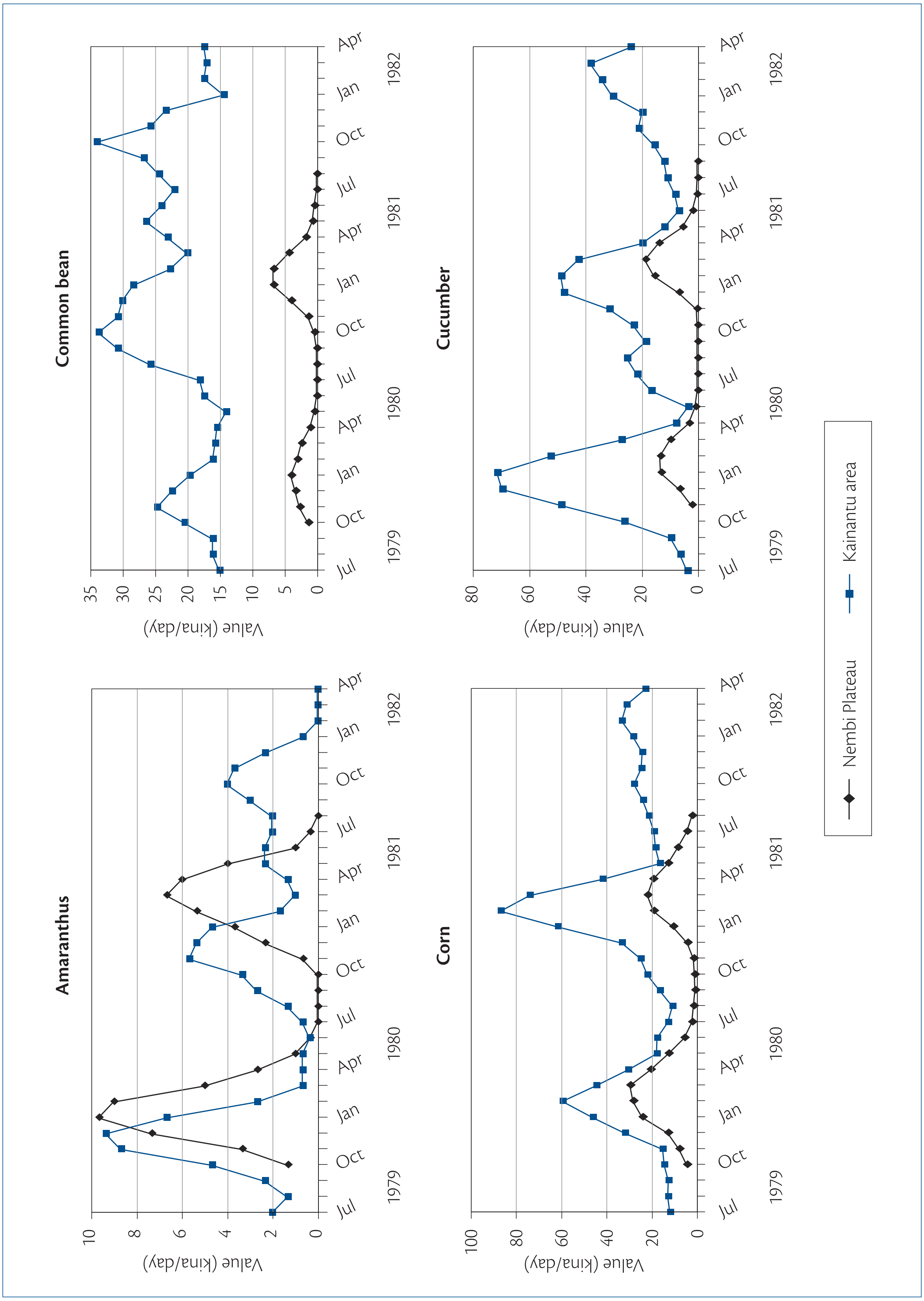

Figure 1.13.2 Availability of amaranthus (*Amaranthus* spp.), common bean (*Phaseolus vulgaris*), corn (*Zea mays*) and cucumber (*Cucumis sativus*) over a 3-year period in local food markets in the Kainantu area, Eastern Highlands Province, and Nembi Plateau, Southern Highlands Province. Data presented as a 3-month running mean. Source: Bourke et al. (2004).

example, on Manus Island. The differences increase at locations further south, particularly in Oro, Milne Bay and Central provinces and the southern part of Western Province (Table 1.13.1). Seasonal differences are also greater where the wettest part of the year coincides with the Southern Hemisphere winter. These conditions occur, for example, in Lae, the Alotau area and the south coast of New Britain. However, even at these locations, the difference in the mean maximum temperature between the coldest part of the year (about July) and the warmest (about February) is only around 4 °C.

Another feature of temperature is the diurnal range, that is, the difference between daytime maximum and night-time minimum temperatures. There are small differences in the diurnal ranges in different locations in PNG, but there is little variation from day to day or even from season to season at any given location. At locations near the ocean the difference between day and night-time temperature is typically about 8 °C. This difference can be less on very small islands where the volume of land is small. In inland locations, for example in the highlands, the diurnal range is typically about 10 °C.

Temperature influences crop growth in a number of ways:

- Minimum or maximum temperatures determine where crops will grow and where they will produce. (These are not always the same. For example, coconut palms grow in the highlands up to 1700–1800 m, but usually bear nuts only up to about 1000 m.)[1]
- Crops generally take longer to mature in a cooler climate. In PNG, this means that crops take longer to mature with increasing altitude.
- One type of temperature extreme, frost, may cause considerable damage to crops. Most crops that grow in PNG are not frost tolerant.

Because altitude has such a strong influence on temperature in PNG, it has a strong influence on where crops will grow and produce. It is possible to define the altitudinal range of crops in PNG. This is illustrated in Figure 1.13.3 and Table A1.13.1 where the usual and extreme altitudinal ranges of 22 crops are shown. The upper or lower altitudinal limits for each species vary somewhat between locations but, for most crops, the upper or lower limit is within ±100 m of the average altitudinal range.

Villagers, especially in the highlands, are very conscious of the altitudinal limits of individual crops. Clan land commonly covers a range of altitudes, so that people can exploit temperature differences to grow a range of crops. For example, a village might be located at 1700 m altitude, with clan land covering the range 1500–2000 m. Crops that require warmer temperatures, such as *marita* pandanus and pawpaw, will be grown only on the lower land, whereas crops that require cooler conditions, such as *karuka* nut pandanus, Irish potato or cabbage, will be located on higher land. Where village land straddles an altitudinal range where a number of crops stop or start to grow, for example at about 1000–1200 m or about 1800–2000 m, it is common for people to speak of 'hot' and 'cold' locations.

For many crops, lower temperatures slow growth and result in a longer growing period. Corn, for example, requires about 90 days to mature below 600 m and 110–120 days at 1600 m altitude. Similarly, sweet potato matures in 3–5 months in the lowlands, but requires 5–8 months at 1600 m and 8–12 months at 2300 m. The longer time to maturity is not necessarily a problem, but is generally a positive condition in most of PNG. This is because, at a given altitude, where soil moisture and nutrients are not limiting growth, the other main environmental factor limiting growth will be lack of bright sunshine. A longer time to maturity allows the plants to accumulate carbohydrate (critical to human nutrition) for longer and the result is often a higher yield. For example, sweet potato yields in the highlands are typically 20–30 tonnes per hectare (t/ha) where the soil is fertile and well drained and the rainfall is adequate. In the lowlands, comparable yields are 15–20 t/ha, although this is achieved in a shorter time.

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1 The figure of 1000 m is the average altitude of 20 locations where coconut usually bears nuts in PNG. Coconut palms occasionally bear some tiny nuts at altitudes as high as 1310 m, but this is exceptional. The altitudinal limit data quoted here was recorded in 1980–1984. Temperatures are rising in PNG (see Section 1.8), as they are worldwide, and some crops are now bearing at a higher altitude.

Temperature also influences flowering and fruiting of some crops. For example, fruit production of pawpaw, guava and carambola (five corner) is not seasonal in the lowlands, but is seasonal in the highlands near the upper altitudinal limit of these crops. Cooler temperatures have an influence on the period that *marita* pandanus fruit is available. In the lowlands, fruit is available all year. With increasing altitude, the period when *marita* is available is reduced. Near its upper altitudinal limit (1600–1700 m), it only fruits for about four months each year (Figure 1.13.4). For some crops however, such as avocado, the fruiting period is similar across a wide range of altitudes. For these crops, we can conclude that temperature does not influence flowering and fruiting.

A number of crops bear more under cooler conditions. Irish potato is one example; it will only bear tubers when the night temperature is less than 18 °C. This occurs at about 800 m altitude in most of PNG, but at slightly lower altitudes in the south of the country. Although tuberisation (the production of potato tubers) occurs at 800 m in PNG, yields are low at this altitude. Irish potato yields best in the main highland valleys (1600–1800 m) and especially at high-altitude locations (above 2000 m). The relationship between temperature and yield of pyrethrum flowers is particularly marked. The yield of pyrethrum flowers increases rapidly with increases in altitude between 1800 m and 2700 m (Figure 5.16.1).

Even though in much of PNG temperature changes may be small from day to day or even from month to month, these small changes can be enough to induce flowering in some plants. This is the case for pineapple, where lower night-time temperatures induce flowering and fruiting. It can be difficult to separate the influence of changes in minimum temperature from changes in daylength (see below) because both occur to a greater degree at locations further from the equator, particularly in the Southern Region. However, where flowering and fruiting occur at about the same time each year, it is more likely that changes in daylength are more important than changes in temperature. Where flowing and fruiting vary a lot from year to year, as they do with pineapple, it is more likely that minimum temperature is the more important factor.

Daylength

Change in daylength has a major influence on when plants flower. The length of the day varies during the course of a year in a predictable manner. Near the equator, for example in Manus and northern New Ireland, daylength does not vary greatly throughout the year. At locations further south, in Milne Bay, Oro and Central provinces and the southern part of Western Province, there is a greater difference in daylength between the period of shortest days (June) to that with the longest (December) (see Section 1.7). These differences are still small compared with places in the temperate zone, for example, in southern Australia.

Table 1.13.1 Average seasonal temperature differences between a low-latitude and a high-latitude location

Location	Latitude, south		Temperature (°C)		
			February	July	Difference
Momote, Manus Island[a]	2°03′	Mean minimum	24.2	24.5	–0.3
		Mean maximum	30.0	29.5	0.5
Samarai, Milne Bay Province[b]	10°37′	Mean minimum	24.7	22.8	1.9
		Mean maximum	31.6	27.0	4.6

[a] Data collated from 20 years of records between 1949 and 1970.

[b] Data collated from 44 years of records between 1891 and 1970.

Source: McAlpine et al. (1975).

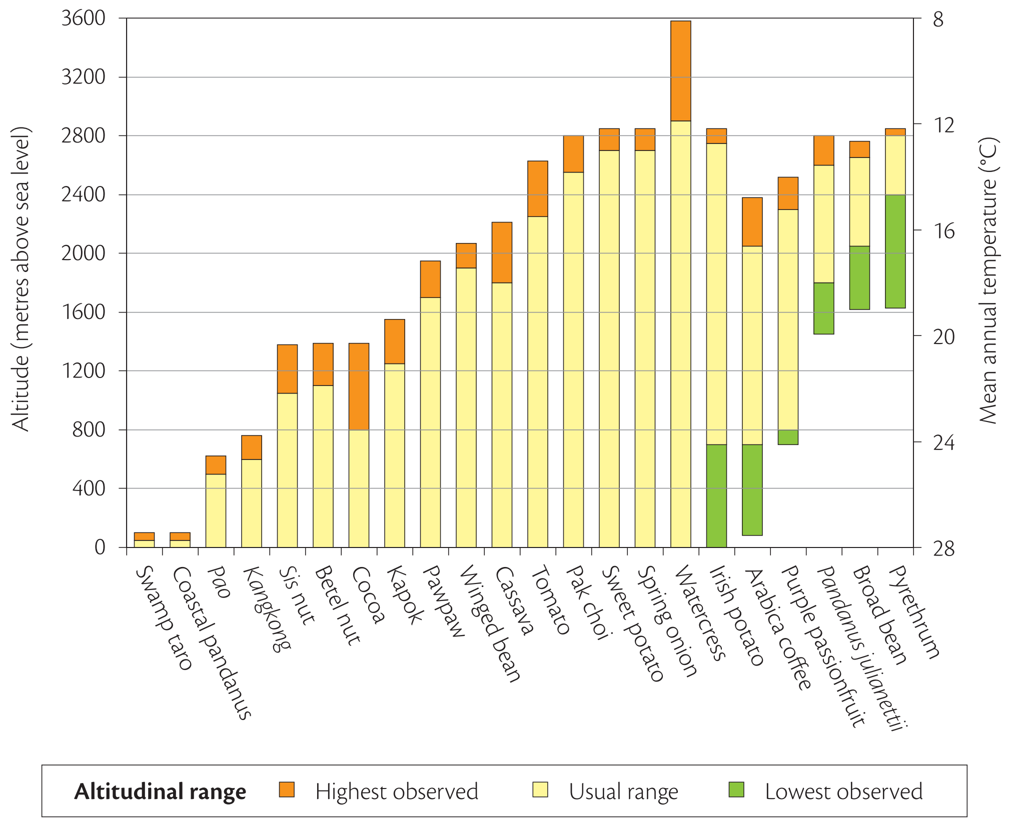

Figure 1.13.3 The usual and extreme altitudinal ranges of 22 crops in PNG. Source: Bourke (1989).

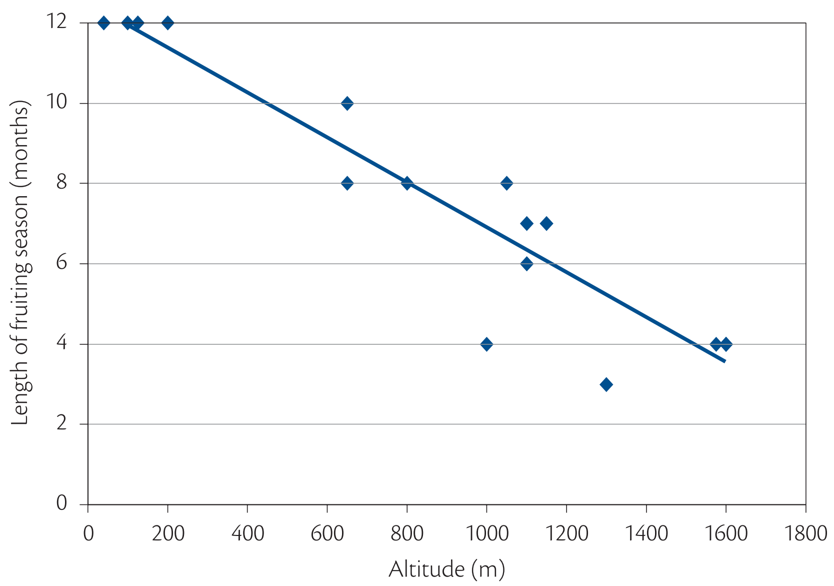

Figure 1.13.4 The length of the fruiting season of *marita* pandanus (*Pandanus conoideus*) versus altitude in PNG. Source: Bourke et al. (2004).

Where a plant species flowers or fruits at about the same time every year, we can infer that it is changes in daylength that induce flowering. This is the case for a number of crops in PNG, including *sis* nut, *marita* pandanus, purple passionfruit and *okari* nut (*Terminalia kaernbachii*). Some species, including breadfruit and Polynesian chestnut (*aila*), appear to produce in a regular seasonal manner from about 8° south of the equator and further south, but fruit in an irregular manner at locations nearer the equator. It is likely that changes in daylength are too small near the equator to induce flowering in a regular way.

Inundation (flooding)

Some locations in PNG are flooded for part of the year (see Section 1.11). This has an important influence on agricultural production in those locations, as many crops cannot grow under flooded conditions. One notable exception is sago palm, which thrives in flooded locations. Sago is a very important food in many places in East Sepik, Sandaun, Western and Gulf provinces. It is notable that sweet potato is a minor crop in those locations, as it only produces where the soil is well drained. Other crops that can tolerate inundation for short or long periods include oil palm, swamp taro, *kangkong*, taro and oenanthe.

A striking feature of PNG agriculture, especially in the highlands, is the use of steep, sloping land for agricultural production. The absence of mechanical or animal-drawn cultivation and the generally low rates of erosion allow the use of steep slopes for agriculture in the highlands. But the most important reason for use of steep land is the desire of villagers to plant sweet potato on well-drained sites. Land that floods seasonally, such as alluvial plains in the wetter season, is often used intensively when it is not flooded and abandoned when it is. In many places along the levee banks of the Sepik and Ramu rivers, villagers plant food gardens as flood levels are falling and harvest before waters rise again around six months later. Villagers favour crops that mature faster, for example, *Dioscorea alata* yam rather than *D. esculenta* yam, because *D. alata* produces tubers faster (see Section 3.12).

Soil fertility

Soil is vitally important for crop growth. It provides support, nutrients, water and aeration for plants. Soil fertility depends on rainfall, the nature of the underlying rock and natural erosion on steep slopes (see Sections 1.9 and 3.7). Soil fertility is commonly reduced by more intensive cropping. As a general rule, soil fertility is reduced faster by intensive cropping in the lowlands than it is in the highlands. This is because higher temperatures in the lowlands cause natural processes to occur at a faster rate than in the cooler highlands environments. Rainfall in the highlands tends to be less intensive than in the lowlands. This means that leaching of elements from soils exposed by cultivation occurs more slowly in the highlands.

Two aspects of soil fertility, the structure and nutrient content, have an important influence on crop growth and yield. For example, under high nitrogen conditions plants tend to grow larger, take longer to mature and yield more. There are exceptions to this, for example, if there is too much nitrogen in the soil, sweet potato will produce a lot of top growth, but the tuber yield may be reduced. Some crops, such as taro, corn, tobacco and common bean, are very sensitive to low levels of plant nutrients. In contrast, some crops, for example cassava, highland *pitpit* and some types of banana (such as Yava, Kalapua or Tukuru), bear reasonably well even when the levels of nutrients are low. The soil structure is more important for some crops than for others. Sweet potato grows best in soils that have a good structure, that is, one that is crumbly and allows water, air and roots to penetrate. If such soils are not available, because they are a heavy clay for example, villagers will improve the structure by tillage (see Section 3.11).

People can influence soil fertility in a number of ways. The first is selecting sites for planting food or cash crops. The second is by deciding when to move from the fallow phase to the garden phase. The third is by modifying the environment in which plants grow.

Villagers select sites for gardens and cash crops on a number of criteria. Sites on flatter land are more likely to be more fertile, but perhaps have poorer drainage than those on sloping land. In the highlands, mixed vegetable food gardens are typically planted on flatter and more fertile land, while sweet potato is commonly planted on better-drained sites, which are often on a gentle to steep slope. These factors are influenced by the nature of the soil, for example, some sites on flat land are well drained. The fallow period is an important determinant of soil fertility (see Section 3.8). Villagers judge how well soil fertility has been restored after the fallow phase by the growth of natural vegetation on the site and not by the period of time the land has been in fallow, although the two factors are related.

Villagers in PNG use a range of methods to improve soil fertility. These include tilling the soil, which is common where the fallow vegetation is grass (Section 3.11); transferring organic matter as green manure (termed 'compost' in PNG) to the soil surface or into a large mound (Section 3.11); planting certain tree species, especially casuarina in the highlands, into food gardens to hasten soil fertility restoration (Section 3.10); and planting a leguminous food, such as peanut, in a rotation with a root crop, especially sweet potato (Section 3.10). People also reduce soil erosion by erecting soil retention barriers or, less commonly, building small terraces to plant crops (Section 3.9). Within a garden plot, people commonly plant those crops that have the highest requirement for fertile soil in sites where fallow vegetation has been burnt and ash has accumulated. In a few locations in the highlands, people burn twigs and leaves of casuarina trees in a pile and plant the crops that demand high soil fertility in those sites, particularly some of the leafy green vegetables.

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1.14 Access to markets and services

A measure of how easy it is to travel from a village in PNG to a service centre or market is defined here as 'accessibility'. It is measured by how long it takes to travel from a village to the nearest service centre or market, and by the level of services available at the service centre.

Before the establishment of a colonial administration in PNG, rural communities grew their own food, built their own houses, manufactured their own clothing, educated their children, used local medicinal plants and magic to treat illnesses and injuries, defended their territory and administered their 'laws'. Although groups of people had trade, ritual and marriage relationships with nearby groups, many individuals did not travel more than a few kilometres from where they were born for the whole of their lives. Their village was the centre of their world.

The colonial state established administrative centres that were places where education and health services and forces of law and order were located. Other places of wealth and employment, plantations and mines, also appeared. The colonial administration made it possible to travel longer distances in safety and to buy and sell commodities, including labour.

When people, commodities and services began to move longer distances in PNG, some places were advantaged over other places. It was easier for some people to receive education and health services, or to sell commodities or labour, because they were closer, in terms of distance, time or effort, to places where the services were offered, or where the commodities or labour were in demand. For them, these places were more accessible.

Because some people had better access to markets and services, in a relatively short span of time they became better educated, healthier and wealthier than other people. Where these differences in *access* to markets or services remain in place, differences in levels of health, education and cash incomes can be expected.

Accessibility classes

Access can be measured in a number of ways, but here accessibility is divided into the following classes:

- Very poor access – more than one day's travel to reach any level of service centre.
- Poor access – between 4 and 8 hours travel to reach a minor service centre.
- Moderate access – between 4 and 8 hours travel to reach a major service centre.
- Good access – between 1 and 4 hours travel to a major service centre.
- Very good access – less than one hour's travel to a major regional centre.

This classification of accessibility is based on the personal experiences of the authors in every district of PNG and takes into consideration terrain, road coverage, road quality, the presence of public road transport and shipping in the late 1990s and the services offered at various centres. Travel is defined as surface travel by a person on foot, in a vehicle or in a boat. Air travel is excluded because most people cannot afford it on a regular basis.

The unit for which accessibility is estimated is the MASP Agricultural System (for more information on MASP see Section 1.15). Accessibility is measured from the centre of the system. Because agricultural systems were defined using attributes that did not include accessibility, some minor anomalies exist. In these cases, which occur close to Lae, Tabubil and Wewak, although it looks on the map as though accessibility to these main centres is poor, it is in fact moderate to very good (Figure 1.14.1).

The estimate of accessibility is based on time to travel and not on the different costs of fuel. Per hour motorboat travel is considerably more expensive than motor vehicle travel.

Accessibility and population

Many people in PNG have good or very good access to service centres. An estimated 46% of the rural population live within four hours travel to a major service centre. A further 38% live within eight hours travel to a major centre (Figure 1.14.2). This situation is the outcome of the colonial administration establishing service centres and building roads in the most populated places.

The greatest numbers of people who have very good access to services live in East New Britain Province and Western Highlands Province. In each of Eastern Highlands, Southern Highlands, Western Highlands and Simbu provinces, more than 200 000 people have good accessibility to a major service centre (Figure 1.14.3, Table A1.14.1). A further 148 000 people in each of East Sepik and Enga provinces live within four hours travel of a major service centre.

Around 16% of the PNG population has poor or very poor access to services. These people live further than four hours travel from any service.

The greatest number of people with very poor access to services live in Sandaun Province, where almost 37 000 people (22% of the provincial population) live more than a day's travel from a minor service centre. More than 20 000 people in each of Southern Highlands and East New Britain provinces are similarly isolated.

Larger numbers of people have poor access to services. In Madang Province 106 000 people live more than four hours from a minor service centre. In each of Southern Highlands, Milne Bay, Western Highlands and Morobe provinces, over 40 000 people have poor access to services.

Summary of access to markets and services

A number of points can be made about access to markets and services in PNG:

- Slightly less than half of the total population of PNG have good or very good access to services.
- Around 16% have poor or very poor access to services.
- In the same province, large numbers of people in one part of the province can have very poor or poor accessibility, and in another part of the province large numbers can have good or very good accessibility. East New Britain Province is an example of this.
- Areas of very poor access to services are located in the Sepik Valley and the highlands of Sandaun Province, along the northern edge of the highlands, in inland Gulf and Central provinces, in south-east Oro Province and in inland East New Britain Province.
- Although the populations of small islands often have moderate access to services because boat travel takes them directly to major service centres, the cost of outboard motor fuel is a severe constraint on their ability to travel. Small boat travel is also dangerous during parts of the year because of weather conditions.

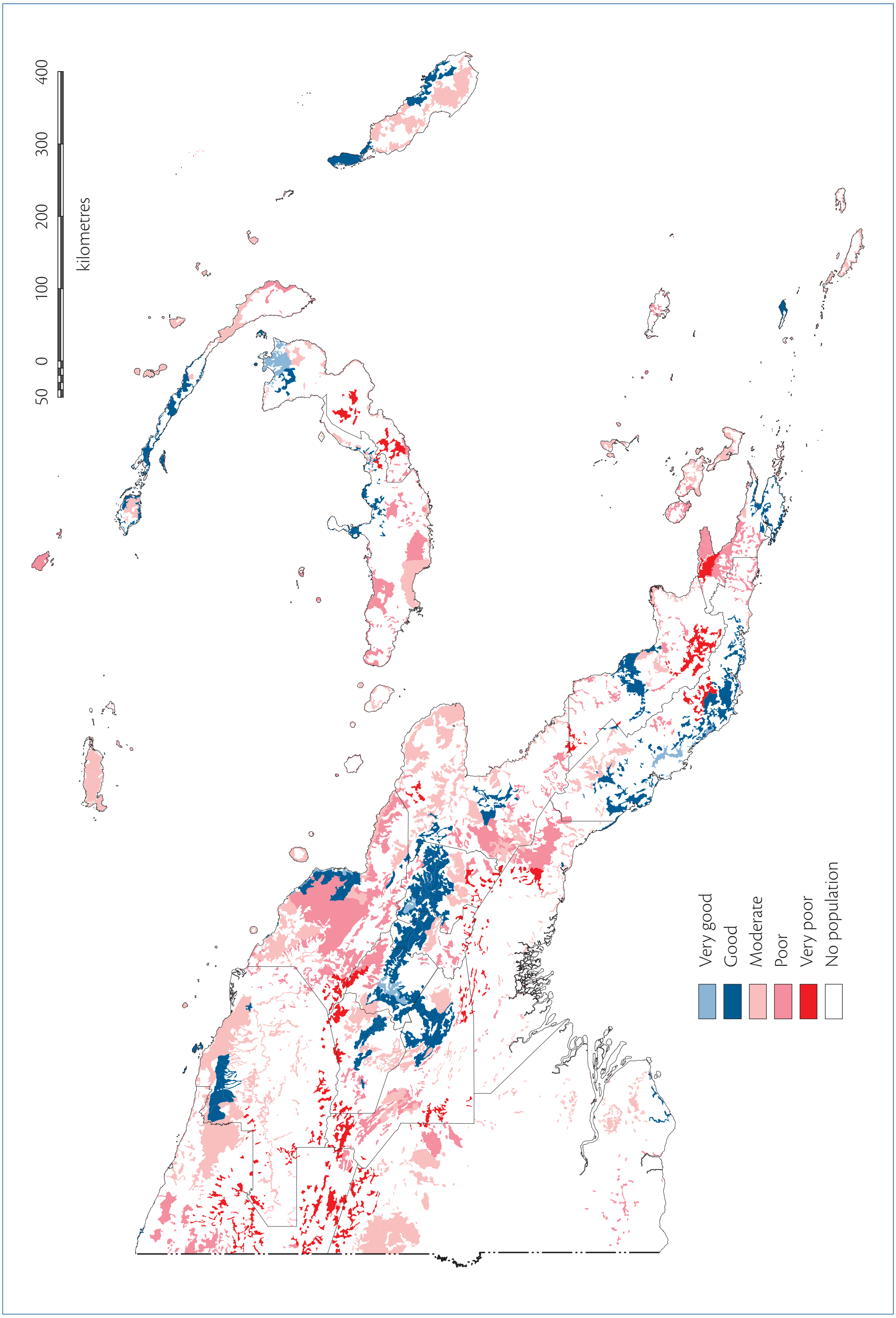

Figure 1.14.1 Access to markets and services. Source: MASP.

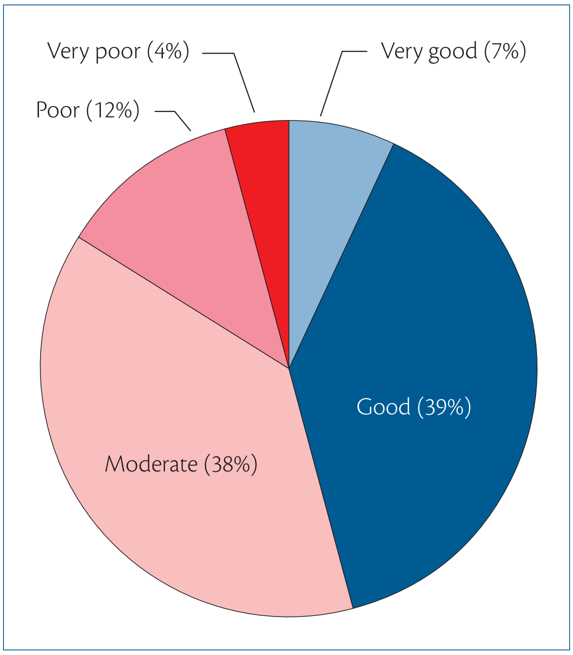

Figure 1.14.2 Access to markets and services by rural population. Sources: NSO (2002); MASP.

- Poor accessibility can be shown to be associated with low incomes and poor levels of health and education.
- Accessibility to some areas has deteriorated over the last 30 years, with the lack of road maintenance, the failure of bridges, and increases in the price of imported fuel for vehicles and boats caused by falls in the international value of the PNG currency.
- Increased fuel prices have caused significant shrinkage in commercial air service networks in PNG since around 2000. This has had the effect of isolating small service centres from the rest of the country, even though accessibility to the centre from surrounding villages may not have changed.

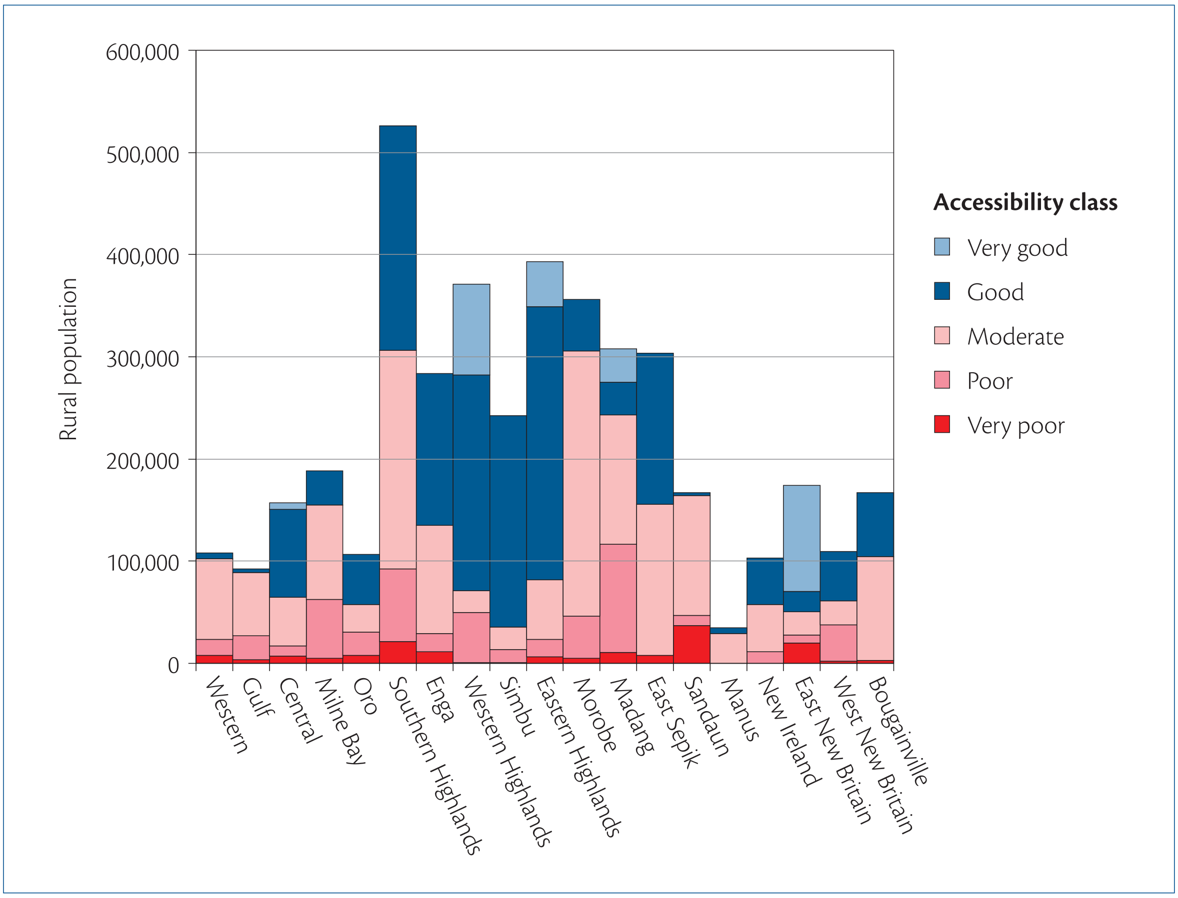

Figure 1.14.3 Rural population by accessibility class and province. Sources: NSO (2002); MASP.

Sources

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1.15 Geographical information systems

PNG is rich in information about natural resources, forests and agriculture. Much of this information is contained in a number of computer-managed databases, some of which are accessible with geographical information systems (GISs) software. PNG has four major GISs relevant to agriculture:

- The PNG Resource Information System (PNGRIS).
- The Mapping Agricultural Systems of PNG Project database (MASP).
- The PNG Land Use maps 1975 and 1996.
- The Forest Resource Information System (FIMS).

A number of sub-national GISs have been developed using methods similar to PNGRIS, including the Madang Resource Information System and the Upper Ramu Resource Information System developed by Lincoln University in New Zealand; and the West New Britain Provincial GIS developed by the Kandrian Gloucester Integrated Development Project. Only PNGRIS and MASP are described here. See the sources at the end of this section for information about other spatial databases in PNG.

Papua New Guinea Resource Information System (PNGRIS)

The Papua New Guinea Resource Information System contains information on natural resources, land use and population distribution. PNGRIS is based on air photo interpretation of the *Skaipiksa* series.[1] Those air photographs were used to extrapolate the detailed information created by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) land system studies to the whole of PNG. This information was mapped onto the 1:500 000 scale Tactical Pilotage Chart (TPC). The TPC map scale is suited to national-level and provincial-level planning, but has limitations for planning at the district level and below.

PNGRIS data is organised into mapping units known as resource mapping units or RMUs. The RMU is a relatively complex area of land characterised by a set of natural resource attributes that are unique. RMUs are defined by combinations of the following attributes:

- Landform (see Section 1.10).
- Rock type (geology).

[1] A series of 1:105 000 scale, black and white vertical air photographs covering all of PNG, taken between 1972 and 1975 by the Royal Australian Air Force.

Box 1.15

The most recent version of PNGRIS was developed by a collaborative project between CSIRO and DAL, funded by AusAID. It uses *MapInfo* (version 4.5) and manages the data using *FoxPro* database management software. A *FoxPro* routine allows users to make queries that pass the outcomes to *MapInfo*, which produces a map. However, this version of PNGRIS has been overtaken by newer, more powerful versions of GIS software. The most recent versions of *MapInfo* will not run with the PNGRIS *FoxPro* software. Most users now access the PNGRIS map and data files directly using *MapInfo* or *ArcView* GIS software packages. The *MapInfo* files can be converted to *ArcView* files using conversion tools available in both packages, but the converted files should be carefully checked for missing records. In addition, in order to conduct complex queries or to produce tables, the dBase file format of the PNGRIS data files enables them to be loaded into most modern database management software packages, including Microsoft *Access* and Microsoft *Excel*. Summary tables from the defining attributes of PNGRIS are presented in McAlpine and Quigley (c. 1995).

- Altitude (as an alternative for temperature – see Sections 1.7 and 1.10).
- Relief (the difference in altitude between the hill tops and the valley bottoms).
- Mean annual rainfall (see Section 1.5).
- Inundation (flooding).
- Province.

The basic defining attribute of an RMU is landform, which is divided by rock type and altitude. The basic RMU is then subdivided by relief, inundation and rainfall. All RMUs are distinguished by province. Thus RMUs with identical attributes are given a different identifier when they cross a province boundary. A total of 4566 unique RMUs are identified for the whole of PNG, including those that are identical on either side of a provincial boundary (Figure 1.15.1, Table 1.15.1).

Population data from the 1980 and 1990 population censuses are listed by RMU in PNGRIS with census unit, census division, district and province tags attached. The authors of this book have added year 2000 census data to PNGRIS. Many of the tables and figures presented in Part 1 of this book are derived from PNGRIS.

PNGRIS also contains information on vegetation, soils, rural population, land use and land use intensity and possible physical constraints to agriculture. However, it is important to understand that the RMUs are not defined on the basis of these attributes. Rather, the additional information is mapped into the RMUs defined on the basis of the seven attributes listed above. Furthermore, information about the spatial distribution of these additional attributes within an RMU is sometimes presented in a complex way. For example, because more than one soil can occur in an RMU, PNGRIS deals with this by allowing each RMU to have up to three soils. Soils that cover less than 20% of an RMU are not listed. If only one soil is listed it covers around 80% of the RMU area. If two soils are listed, the first covers 40–60% of the RMU and the second 20–40%. If three soils are listed, the first covers 30–50% of the RMU area and the second and third 20–40%. Vegetation is presented in a similar way. It is not uncommon for users of PNGRIS to misunderstand this approach.

Because some data in PNGRIS is dependent on other data, care must be taken when analysing the relationships between attributes. For example, the estimate of inundation relies heavily on the type of vegetation, and altitude is an alternative for temperature. Information about soils is created from a combination of field observations, extrapolation from these observations to RMUs with similar environmental characteristics, and field experience.

Thus it would be a serious mistake to use PNGRIS to investigate relationships between soil type and slope, or vegetation and flooding.

The information in PNGRIS is coded. That is, a number is used to represent a class of attribute. The codes are contained in Appendix III in Bellamy (1986) (reprinted in 1995).

The Mapping Agricultural Systems of Papua New Guinea Project (MASP)

The Mapping Agricultural Systems of Papua New Guinea Project identified, described and mapped 'agricultural systems' for the whole of PNG. The project was carried out by the Land Management Group in the Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University.

The primary objective of MASP was to identify and describe agricultural activities in a way that would allow them to be assessed against the natural resource attributes of PNGRIS, in order to examine the question of agricultural sustainability under conditions of rapid demographic and socio-economic change. MASP uses the same 1:500 000 scale Tactical Pilotage Chart as PNGRIS and was designed to be compatible with PNGRIS. However, a decision was made to map agricultural systems independently of PNGRIS RMU boundaries so that

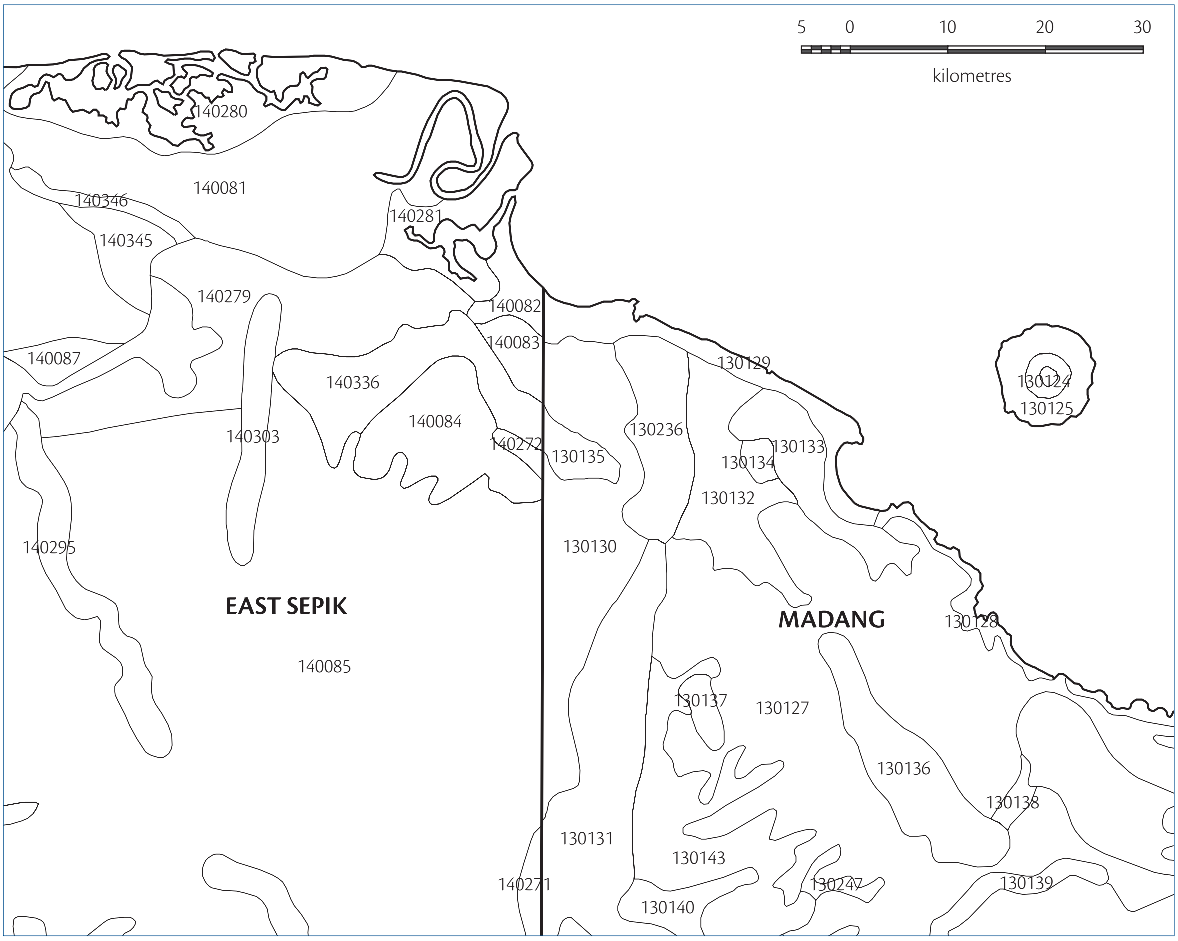

Figure 1.15.1 The PNGRIS GIS map showing resource mapping unit (RMU) numbers for part of East Sepik and Madang provinces. **Note:** To avoid cluttering the map, not all province RMU numbers are shown. Source: PNGRIS.

an analysis of the associations between agriculture and natural resources would be based on two independent databases.[2]

The mapping unit of MASP is the agricultural system (AGSYS). Agricultural systems are identified as areas in which the combinations of six agricultural activities are unique. Field observations and interviews with villagers during traverses across every district in PNG between 1990 and 1995, complemented by published and unpublished literature, supplied the information used to identify agricultural systems.[3]

[2] The MASP GIS is available in both *MapInfo* and *ArcView* formats. The data files are held in the same dBase file format as PNGRIS.

[3] The exception is Bougainville Province, which was not visited at that time because of the civil war (1989–1997). Identification of agricultural systems in Bougainville Province was based on interviews conducted in 1996, updated by fieldwork in 2002.

The attributes used to define an AGSYS are:

- Fallow vegetation – the type of vegetation cleared from garden sites at the beginning of planting (see Section 3.8).
- The number of times land is planted before it is fallowed.
- The period of time that land is fallowed.
- The most important staple food crops (see Section 3.1).
- Techniques used to maintain soil fertility (other than a long fallow) (see Sections 3.7–3.12).
- Segregation of crops within or between garden sites.
- Province.

Table 1.15.1 Part of the PNGRIS database showing records for resource mapping units (RMUs) for Madang and East Sepik provinces

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
130269	13	MAD	269	5	5	48	145	17	45	51	23	0	6	5	5	3	6	3	4	0	0	1	0	0
130270	13	MAD	270	2	4	57	145	38	27	51	13	0	6	5	4	2	4	3	3	0	0	1	95	0
130271	13	MAD	271	2	5	38	145	50	74	51	15	0	5	0	4	2	3	3	3	0	0	1	0	0
140001	14	ESK	1	2	3	11	143	16	4	6	15	0	1	0	1	1	4	3	4	1	1	95	0	0
140002	14	ESK	2	2	3	13	143	18	11	6	15	0	1	0	1	1	4	3	4	1	1	95	0	0
140003	14	ESK	3	2	3	19	143	34	46	51	31	13	5	6	5	1	4	3	4	0	0	1	95	0

Key

A Province RMU number (unique in PNG)	**J** Area of RMU (km^2)	**S** Rainfall seasonality code
B Census province code	**K** Landform code	**T** Rainfall deficit code
C Province	**L** Lithology code (rock type) 1	**U** Inundation code
D RMU number (unique in province)	**M** Lithology code 2	**V** Inundation extent code
E 1990 census district code	**N** Slope code 1	**W** Vegetation code 1
F Latitude of RMU centre (degrees)	**O** Slope code 2	**X** Vegetation code 2
G Latitude of RMU centre (minutes)	**P** Relief code	**Y** Vegetation code 3
H Longitude of RMU centre (degrees)	**Q** Altitude code	
I Longitude of RMU centre (minutes)	**R** Annual rainfall code	

Source: PNGRIS.

Agricultural systems are identified only for those parts of PNG that are classed as 'cultivated' in PNGRIS (see Section 1.2). Many PNG agricultural systems exploit microenvironments and the outcome is a complex spatial pattern of agricultural activities, often on a scale too small to be mapped at 1:500 000. This problem is dealt with by the introduction of subsystems. The subsystem boundaries are not mapped, but information is presented for all subsystems within an AGSYS, and an estimate is provided of the area occupied by each subsystem. Text notes described the relationship between the environment and the subsystem locations.

Like PNGRIS, MASP contains additional information, mapped into AGSYSs, that is not used to define the boundaries of the agricultural system. Another 102 attributes are mapped into AGSYSs.

Excluding systems that are identical on both sides of a provincial boundary, a total of 287 unique AGSYSs were identified for PNG (Figure 1.15.2, Table 1.15.2). The information for every province, including the codes used in the dBase files and GIS, has also been published in a series of Working Papers.[4] The MASP database was used to generate most of the tables and figures presented in Part 3 of this book.

4 There are 22 papers in the series: a two-volume summary (Working Paper No. 1), a paper for each province (19 papers), a technical information paper and a separate bibliography. The Working Papers have been distributed widely within PNG and are available in book form and as *Acrobat* PDF files.

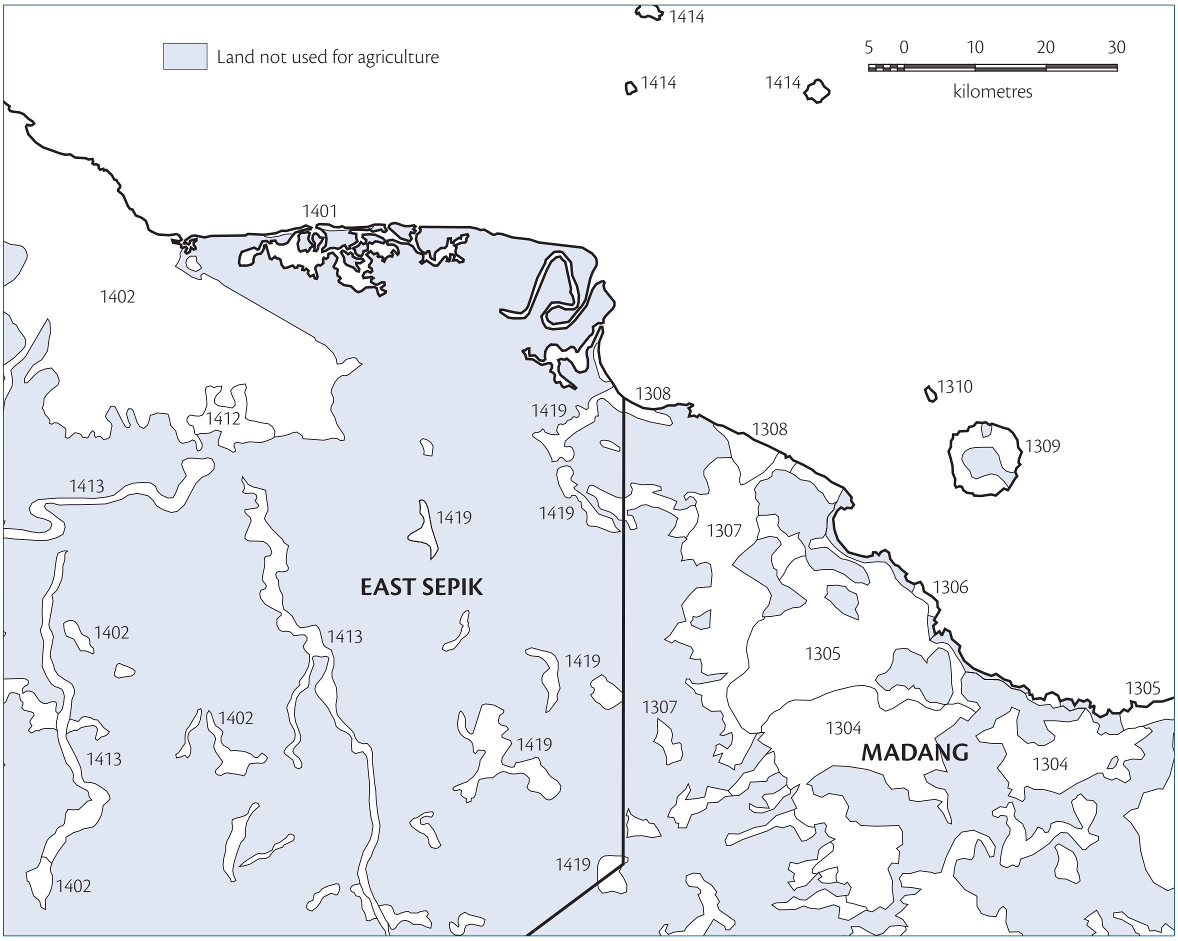

Figure 1.15.2 The MASP GIS map showing agricultural system (AGSYS) numbers for part of East Sepik and Madang provinces. **Note:** The shaded areas represent land that is not used for agriculture (see Section 1.2) and is excluded from MASP. Not all agricultural system numbers are shown. Source: MASP.

Table 1.15.2 Part of the MASP database showing records for agricultural systems (AGSYSs) for Madang and East Sepik provinces

A	B	C	D	E	F	G	H	I	J	K
1324	1	2	20	150	2	4	0	2	2	02-05
1325	1	2	40	100	3	4	0	2	2	00
1326	1	2–5	150	650	5	5	0	2	1	05–13
1327	1	1	2000	2600	2	2	2	2	4	11
1328	1	1–2	300	1600	2	5	1	2	2	11
1329	2	1	1600	2000	3	5	2	3	3	11
1330	1	5	800	1800	3	5	0	3	2	11
1331	2	5	200	450	1	1	0	2	2	02–11
1332	1	5	600	2200	5	4	0	2	1	11
1401	1	1	0	10	1	0	0	0	0	00
1402	1	1–2–3–4	0	800	5	5	0	3	1	09

Key

A	Agricultural system identifier based on province code (e.g. 13 for Madang) and the AGSYS number in that province
B	Number of subsystems that occur within the system (up to 3)
C	1990 census district code
D	Lowest altitude of land used for agriculture in the AGSYS (metres)
E	Highest altitude of land used for agriculture in the AGSYS (metres)
F	Slope code
G	Most common fallow type code
H	Significance of short fallows (<12 months) code
I	Length of fallow period code
J	Cropping interval code
K	Most important staple crops code

Source: MASP.

The main fieldwork for the MASP database was conducted 10–15 years ago (1990–1995). Some field checks by other, independent observers have found that, in general, the information remains current. The information that is becoming dated is that on sources of cash income.

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PART 2

Food Production, Consumption and Imports

R. Michael Bourke, John Gibson, Alan Quartermain, Kate Barclay, Bryant Allen and Jean Kennedy

2.1 Food in Papua New Guinea: an overview

Food is made up of three major components – proteins, carbohydrates and fats – and each is necessary for growth and healthy living. Although all three provide energy, carbohydrates, which consist of starches and sugars, provide the highest proportion of the *food energy* (or fuel) that human bodies need to function. Protein, used for building and repairing the body, comes from animal products such as meat, fish, and milk, but also from grains and vegetable foods. Small quantities of fats and oils are also important in a balanced diet. They provide more food energy per gram than either carbohydrates or protein.

Staple foods provide most of the carbohydrate (and thus food energy). In PNG the staple foods are starchy root crops, sago and banana. The amount of energy in these foods depends on how much protein, carbohydrate and fat they contain. The main sources of fats and oils in PNG are meat (pigs, fish and other animals), coconut, *marita* pandanus and imported vegetable oil.

This section provides an overview of food sources in PNG and introduces the more detailed sections that follow.

Estimates of energy and protein production and consumption

Most of the food consumed in PNG is produced within the country. In 2006 it was estimated that 83% of food energy and 76% of protein consumed in PNG was produced in PNG. The balance was imported (Figure 2.1.1). In 1996 it was calculated that locally grown food provided 80% of the food energy consumed in PNG; rural villagers obtained 84% of their food energy from locally grown food and urban people obtained 50%.

The 1996 and 2006 estimates are based on different measures, so it is not possible to conclude that the proportion of food energy derived from local sources increased or decreased during that decade. Nevertheless, it is almost certain that people are now obtaining more of their food requirements from food produced within PNG than they did in the mid 1990s. This is because after 1997 the PNG kina lost value against other currencies, the price of imported rice increased and its consumption decreased (see Part 4 and Section 2.7). As a result, consumption of locally grown food increased.

The 1996 Household Survey found significant differences in food consumption between urban and rural households. Urban people consumed more rice, wheat-based foods, soft drink and beer, and less root crops and banana (Table 2.1.1). Consumption estimates from the 1996 Household Survey and estimates of the quantities of the most important foods consumed in 2006 are similar (Table A2.1.1). Most of the differences that exist between the two estimates are probably errors in the data but some reflect real changes, such as the increased consumption of foods prepared from flour.

Plant foods grown in PNG – sweet potato and other root crops, banana, sago, sugar cane, coconut, vegetables, peanuts, fruit and nuts – provide an estimated

76% of food energy and 57% of protein consumed by rural and urban people (Figure 2.1.2). Imported rice, and imported wheat that is manufactured into bread, biscuits and noodles in PNG, provide a further 14% of food energy and 17% of protein. Meat and fish, most of which is produced in PNG, contribute 6% of food energy, but 25% of protein in people's diets. Smaller amounts of food energy and protein come from commercially refined sugar (produced in the Ramu Valley), imported and locally produced vegetable oil, imported animal fat, imported dairy products and other minor food products.

Diet

People's diets vary across the country, particularly between rural and urban areas. The broad pattern is that most food energy in rural areas comes from root crops, banana and sago, with coconut, other nuts and green vegetables making a small but significant contribution to energy and a greater contribution to the intake of other nutrients, particularly protein.

Purchased foods based on imported rice, flour and vegetable oil typically provide about a fifth of the food energy in people's diets, considerably more in urban areas and considerably less in remote locations. Diets change with economic development, urbanisation and increasing cash incomes. Imported rice and wheat-based foods become more important and the consumption of cooking oil, tinned meat and tinned fish increases.

Changes in diet have been observed in a number of places in PNG over the past 50 years. For example, the contribution of sweet potato to dietary energy at Yobakogl village in the Sinasina area of Simbu Province fell from 76% in 1956 to 53% in 1981 (Figure 2.1.3). Over this period, the proportion of food energy derived from rice, wheat-based foods and corn increased from 4% to 22%. These changes were associated with increases in cash income from coffee sales. Similarly, on Ontong Java Atoll, the contribution of imported foods increased from 27% to 51% between 1971 and 1986, while the relative importance of locally produced coconut, fish, swamp taro and taro decreased. Changes have also occurred in the consumption of locally grown foods.

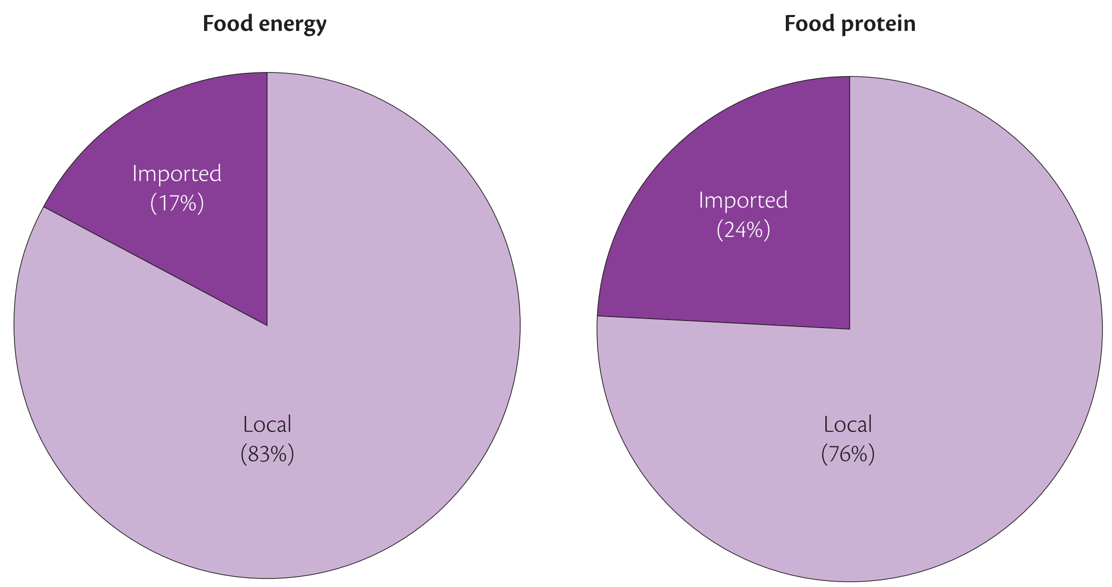

Figure 2.1.1 Proportion of energy and protein derived from locally produced and imported foods, 2006.
Source: Table A2.1.1 and author's calculations.

For example, in the late 1960s taro was the single most important garden food on Karkar Island in Madang Province, but by the early 1990s banana and Chinese taro had also become important foods.

Fresh food markets

Most food grown in PNG is consumed in the producing household. But many people also sell some of the food that they grow at local and regional fresh food markets (see Section 5.3). Fresh food markets are numerous in all urban and many rural locations. They are an important source of food in urban areas and as a source of income in rural areas. The total volume of fresh food sold through all food markets is not known, but the amount of fresh food sold in Port Moresby in 2005 was estimated as 15 000 tonnes. Information from the Mapping Agricultural Systems of PNG Project (MASP; see Section 1.15) illustrates the importance of domestically marketed food. It suggests that the amount of cash earned from selling fresh food is exceeded only by cash earned from coffee sales (Figure 5.1.1). A large number of foods are marketed, the most common being root crops, particularly sweet potato; peanut; banana; coconut; fruit such as mango, pawpaw and pineapple; and many types of green vegetables. Fresh food is not exported from PNG because of uncompetitive pricing, the generally poor presentation of the produce, expensive or unavailable transport, and quarantine barriers.

Table 2.1.1 Proportion of rural, urban and total population consuming different foods during the PNG Household Survey in 1996 (%)

Food	Rural	Urban	Total population
Greens	74.3	78.9	75.0
Sweet potato	65.0	33.6	60.2
Rice (imported)	25.8	87.4	35.1
Banana	33.6	38.7	34.3
Coconut	28.4	34.2	29.2
Biscuit/bread/flour/scone	14.4	74.6	23.5
Taro and Chinese taro	23.9	9.6	21.7
Sago	13.3	18.9	14.2
Tinned meat	5.9	51.7	12.8
Legumes	12.7	7.8	12.0
Tinned fish	9.1	24.5	11.4
Yam	12.5	4.8	11.3
Fresh fish, shellfish	7.1	28.2	10.3
Chicken	4.1	26.5	7.5
Pork, beef, other meat	6.4	9.9	6.9
Cassava	6.9	4.3	6.5
Lamb and mutton	5.0	13.7	6.3
Bush meat	1.8	1.5	1.7

Source: Gibson (2001:47).

Main sources of food

Food in PNG has five main sources:

- Local food plants.
- Imported plant food.
- Local industrial-scale production.
- Local foods of animal origin.
- Imported foods of animal origin.

Local food plants

PNG villagers grow or harvest about 400 plant species for food. Many of these foods are consumed in small quantities or in a limited number of places. Some are grown only for sale while others are grown just to try them out. Most people regularly grow between 30 and 80 species of food crops and many varieties of the most important species (see Section 2.3). Most foods plants are cultivated in gardens or in orchards, but food is also harvested from self-sown plants in food gardens, in fallow regrowth (see Section 3.8), in swamps, in unmanaged forest, or in grasslands. Food plants may be grouped into root crops, sago and banana (the staples) (see Section 3.1), leafy green and other vegetables (Section 3.2), fruit (Section 3.3), nuts (Section 3.4), sugar cane and stimulants (Section 3.5).

Sweet potato is by far the most important staple food in PNG. It provides around two-thirds of the food energy from locally grown food crops and is an important food for 65% of rural villagers. Other important staple foods include banana, sago, cassava, yam, taro and Chinese taro (Figure 2.2.2, Table 2.2.1). Domestic rice production is negligible compared with that of root crops, sago and banana, and is less than 1% of the quantity of imported rice (see Sections 2.5 and 2.7).

Many species of leafy green vegetables are eaten in PNG, and they are consumed daily (Table 2.1.1). The most important greens are pumpkin tips, *aibika*, amaranthus, rungia, *tulip*, oenanthe, cabbage, fern fronds, rorippa, Chinese cabbage, choko tips and taro leaves. Important non-leafy green vegetables include corn, highland *pitpit*, lowland *pitpit*, common bean, cucumber, winged bean, snake bean, pumpkin fruit and spring onion (Table 3.2.1).

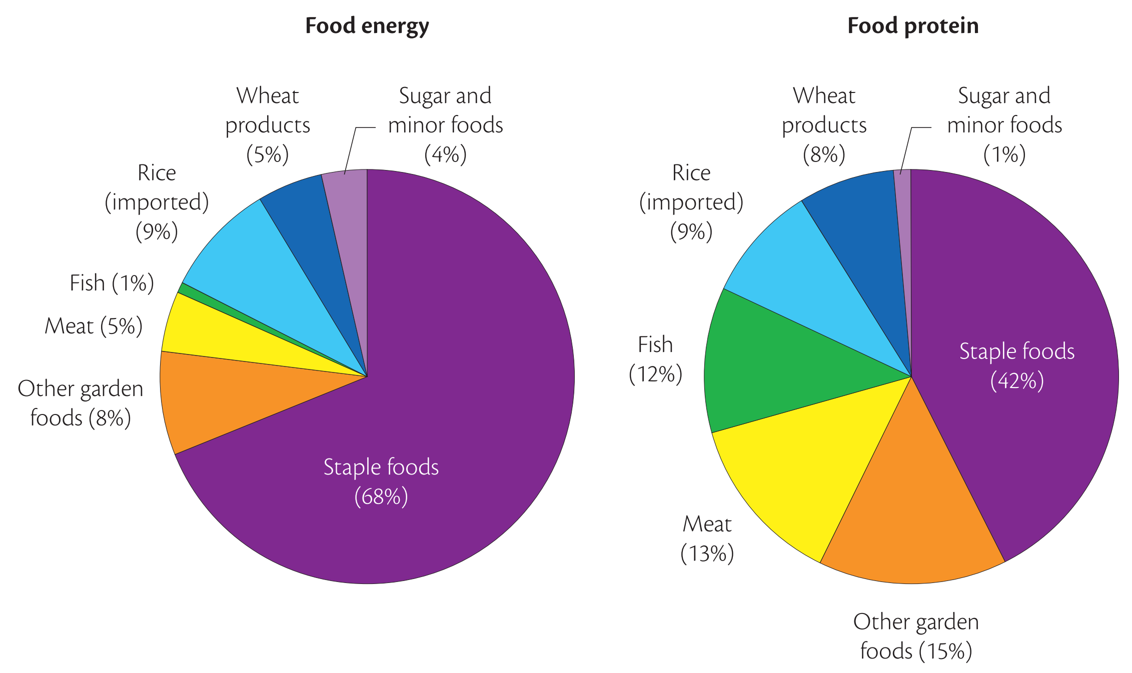

Figure 2.1.2 Source of energy and protein by main food groups, 2006. Source: Table A2.1.1 and author's calculations.

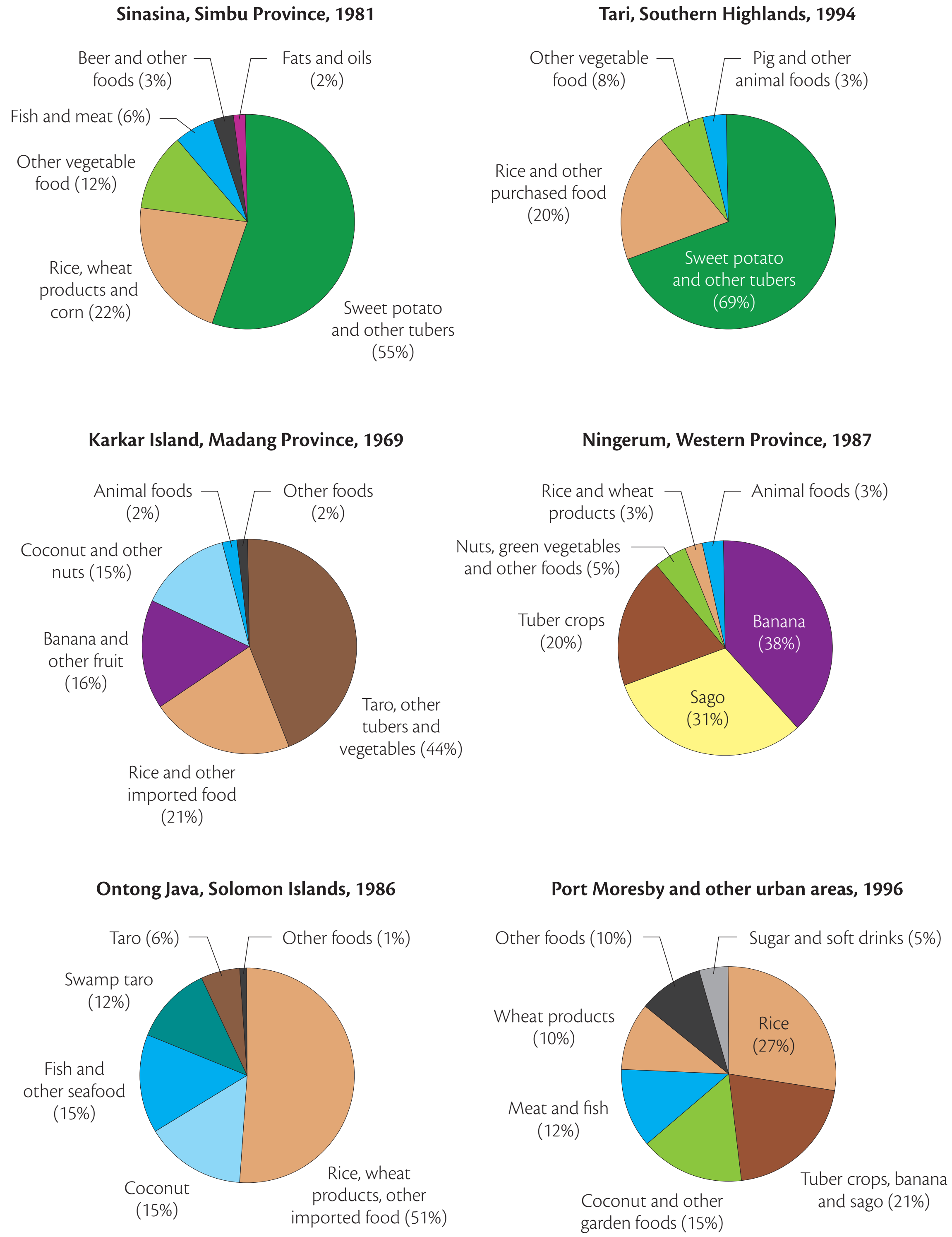

Figure 2.1.3 Proportion of total energy from different foods in selected locations. **Note:** Ontong Java is an atoll group in Solomon Islands near the international border with PNG. This data was used because it is of higher quality than that available for atolls in PNG and is likely to be representative of PNG atolls. Sources: Sinasina: Harvey and Heywood (1983); Tari: Umezaki et al. (1999); Karkar Island: Norgan et al. (1974); Ningerum: Ulijaszek (1992); Ontong Java: Bayliss-Smith (1986); Port Moresby: Gibson (2001:43).

Many fruits are eaten, including pawpaw, *marita* pandanus, pineapple, mango, watermelon, *ton*, Malay apple, guava, orange and passionfruit (Table 3.3.1). The most important nut crops are coconut and peanut.[1] Other nuts, which are commonly eaten seasonally, include breadfruit seed, *karuka* nut pandanus, *galip*, Polynesian chestnut (*aila*), sea almond (*talis*), *pao* and *okari* (Table 3.4.1). Sugar cane is another important food. Consumption of village-grown sugar cane is estimated to be 60 kg of cane per person per year (Table A2.1.1).

A number of stimulants are widely used, particularly betel nut, betel pepper, tobacco and, less commonly, marijuana, but they contribute almost nothing nutritionally (see Section 3.5).

Imported plant food

Rice and wheat are the most important imported foods (see Section 2.7). Rice imports have averaged 152 000 tonnes per year since 1990 and wheat imports 117 000 tonnes per year. It is possible that rice consumption per person in PNG has reached a plateau, although it increased in 2006 (to 184 000 tonnes, or 30 kg/person/year). Wheat is milled in PNG to produce flour that is used to manufacture commercial quantities of bread, biscuits and 'instant' noodles for sale in retail outlets. Individuals also use flour to make 'scones' from unleavened dough deep-fried in vegetable oil. Since 1998, per person wheat imports have been increasing while rice imports have decreased or been static (Figures 2.7.2, 2.7.3).

The 5000–6000 tonnes of vegetable oil imported annually (Table 2.1.2) is supplemented by locally refined coconut and palm oil.

A small quantity of fresh fruit and vegetables is imported from Australia and New Zealand (see Section 2.8). The quantity imported has been declining and is now less than 6000 tonnes per year (about 1 kg/person/year). Onions, potatoes, apples, oranges and peas are the most important commodities imported (Table 2.1.2, Figure 2.8.2). Potato imports declined significantly from around 1980 because of increased production in the highlands, but have increased again following the outbreak of potato late blight disease in the highlands in 2003.

Local industrial-scale production

Six foods are produced on an industrial scale in PNG: coffee, cocoa, coconut (for copra oil), oil palm (for palm oil), sugar and tea. Most of the production is exported (see Part 5), with sugar cane the only industrial crop grown primarily for the domestic market (see Section 5.10). Small quantities of locally grown coffee, tea and refined palm oil are also consumed, but domestic consumption is a very small proportion of total production.

Local foods of animal origin

Fish, shellfish, pigs, chickens and cattle are the most important animal foods consumed in PNG. Much less important are rabbit, duck, sheep, goat and dog. Wild pigs, bandicoots and other small mammals, birds and insects are hunted and collected widely and are important foods in more remote locations.

Fish, shellfish and other marine animals, such as octopus and turtle, are caught and eaten. Fish is a major dietary item for villagers living on the coast and along major rivers. The per person consumption of fish in PNG is much lower than in many other Pacific and Asian countries (see Sections 5.9 and 2.10).[2]

The most important animal food is the domestic pig, with an estimated 1.8 million pigs being raised in PNG villages. Commercial pig production is relatively small. An estimated 1.5 million chickens in PNG villages are used for meat and eggs but, in most villages, chickens scavenge and production is low. The commercial chicken sector is more productive. Village cattle projects that took the form of small-scale

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1 In this book coconut is grouped with the staple food crops (Section 3.1) and peanut with the vegetables (Section 3.2).

2 Estimates of fish and other seafood consumption in PNG vary widely. The National Fisheries Authority estimates consumption at 25 000 to 50 000 tonnes per year (5–10 kg/person/year) (see Section 5.9). However, other estimates for fish and seafood caught locally are as high as 120 000 tonnes per year (24 kg/person/year) (see Section 2.10). Figures of 50 000 tonnes (8 kg/person/year) for fresh and smoked fish and 15 000 tonnes (2 kg/person/year) of tinned tuna were used here to calculate the contribution of fish to the national diet (Table A2.1.1).

enclosures planted to pasture grasses collapsed in debt and unmanageable stock in the 1980s. Eighty per cent of the national cattle herd, estimated at around 80 000 head, is today maintained on large holdings, with only 20% owned by villagers (Table 2.6.3).

A significant amount of wildlife is hunted or gathered and consumed each year, particularly in locations where the human population density is low. Somewhere between 0.8 and 1.6 million people derive significant dietary protein from wild animals and consume 4–8 million vertebrate animals a year. The estimated replacement value of this wild or bush meat with imported tinned mackerel or mutton flaps was K75 million in 2005.

Imported foods of animal origin

Animal foods imported into PNG are sheep meat, beef and offal (lungs, liver, kidneys and other internal organs) and mackerel and tuna (see Sections 2.9 and 2.10). Over the past 20 years significant changes have taken place, first in the composition of meat imports, with sheep meat becoming more important than beef (Figure 2.9.2) and, second, in a decline in consumption of tinned meat, fresh meat and tinned mackerel and an increase in consumption of tinned tuna. These changes were driven by the relative costs of meat and fish, with a small tin of tuna retailing for about half the price of a comparable tin of meat.

Table 2.1.2 Volume and value of imports of meat, fish, vegetables, fruit, dairy products, animal fat and vegetable oil, 2002–2004[a]

Imported food	Volume (tonnes)			Value (K'000)		
	2002	2003	2004	2002	2003	2004
Sheep meat	20,528	16,845	22,046	76,501	80,094	83,798
Beef	6,615	3,806	3,028	34,535	26,347	25,679
Offal	1,658	1,706	2,382	6,656	8,493	8,506
Pig meat	85	192	200	481	1,244	2,031
Other meat	77	92	118	302	608	1,037
Fish[b]	7,986	9,324	8,903	26,919	24,673	26,652
Onions	1,263	977	955	2,171	2,355	2,294
Potatoes[c]	161	735	502	471	2,118	2,469
Apples	624	674	428	3,489	3,330	2,806
Citrus	225	306	222	1,235	1,396	1,248
Other fruit and vegetables	784	772	805	5,297	5,250	4,845
Milk and other dairy products	5,920	5,938	4,196	32,273	26,161	31,373
Butter and dairy spreads	678	673	448	6,169	6,644	6,283
Animal fat[d]	–	–	6,182	–	–	12,264
Vegetable oils[d]	–	–	5,477	–	–	23,527

[a] NSO figures for volume and value of food imports are generally lower than those from other sources, including data from the exporting countries, where there is an overlap in coverage (see Tables A2.8.1, A2.9.1, A2.10.1). This suggests that not all import data are recorded in the NSO database.

[b] The figures for fish imports exclude bait fish (average 1150 tonnes/year).

[c] The figures for potato imports exclude seed potato (average 8 tonnes/year).

[d] The source for animal fat and vegetable oils is McGregor (2006: Table 14).

Source: National Statistical Office of PNG.

Around 4000–6000 tonnes of dairy products are imported annually (about 1 kg/person/year), mainly from Australia and New Zealand (Table 2.1.2). UHT (ultra heat treated), fresh and powdered milk account for about 80% of dairy imports. Other imported dairy products are butter, dairy spreads, yoghurt and cheese. About 6000 tonnes of other animal fat, such as lard, is imported each year and is used in baking and other food preparation.

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2.2 Staple food crop production

Estimates of staple food crop production

In PNG the staple foods are mainly starchy root crops, sago and banana. Estimates of staple food crop production were made in 1961–1962 as part of the Survey of Indigenous Agriculture (see Section 6.5), and in 1996 from the PNG Household Survey (see Section 2.1). New estimates were made for the year 2000, drawn from data from a nationwide survey of village agriculture conducted in 1990–1995 (MASP; see Section 1.15). The MASP survey identified 342 agricultural systems. To generate estimates of staple food crop production, the proportion of garden area devoted to each food crop in each agricultural system was combined with population data from the 2000 National Census, average garden area planted per person per year, and average crop yield in different environments (Table 2.4.1) (see Box 2.2).

Total staple crop production in 2000 was estimated as 4.5 million tonnes per year, with a food energy content of $18\,196 \times 10^9$ kilojoules (kJ)[1] (Table 2.2.1). This is equivalent to 870 kg/person/year of staple food crops and contains food energy of 9600 kJ/person/day. A significant amount of sweet potato grown in the highlands is fed to domestic pigs, so the estimate of energy produced is not directly comparable to an estimate of the energy consumed by people.

The 2000 estimates were checked by comparing the figures with the daily energy requirements of the population.[2] The check indicated that the new figures are reasonably accurate estimates of production

1 A kilojoule is the internationally recognised unit of measurement for the energy value of food. A common term for unit of energy was the Calorie. One Calorie equals 4.1868 kilojoules.

2 'Daily energy requirement' is the amount of energy that humans need to live and perform active lives. It varies a lot between people and the figure used here (11 160 kJ) is an average one for Papua New Guineans.

Box 2.2

Annual production of each staple crop (tonnes)	=	Proportion of garden land planted with each crop	×	2000 rural population in each agricultural system	×	Average garden area planted per person per year (ha)	×	Average crop yield adjusted for environment (t/ha)

of staple food crops. The figures presented in this section are for *total* production, that is, they include food that is wasted, fed to livestock (especially pigs in the highlands), and kitchen scraps.

Sweet potato dominates food production in PNG. It accounts for almost two-thirds (64%) of production of staple food crops by weight and 63% of food energy production (Table 2.2.1). No other staple food crop contributes more than 10% of the total national production by weight or food energy. The contribution by weight for the more important foods is: banana (9.7%), cassava (6.0%), yam (6.0%), *Colocasia* taro (5.1%), Chinese taro (5.0%), coconut (2.2%) and sago (1.8%). A number of minor crops make a very small contribution to total staple food crop production, with locally grown rice responsible for only about 0.01%. The proportions of food energy are similar to those for production by weight; however, the contribution to food energy is greater for sago (6.8% of energy produced from staples), coconut (3.5%) and rice (0.03%) because these foods have a higher energy value per unit weight than banana or the root crops.

Production of main staple food crops

Sweet potato dominates food production in the highlands, but is also an important food in many lowlands locations, where it has increased in importance over the past 60 years. Sweet potato is grown in almost every agricultural system in PNG, with some

Table 2.2.1 Estimated production of 18 staple food crops in 2000

Crop	Weight (tonnes)	Weight (%)	Energy (kJ x 10^9)	Energy (%)
Sweet potato	2,871,851	63.57	11,422.68	62.77
Banana	436,496	9.66	1,260.98	6.93
Cassava	271,894	6.02	1,115.61	6.13
Colocasia taro	229,088	5.07	748.14	4.11
Chinese taro	226,536	5.01	739.81	4.07
Lesser yam (*Dioscorea esculenta*)	180,370	3.99	656.99	3.61
Coconut	100,929	2.23	633.88	3.48
Greater yam (*D. alata*)	91,358	2.02	294.54	1.62
Sago	82,962	1.84	1,240.00	6.81
Irish potato	18,759	0.42	55.77	0.31
Taro (*Alocasia*)	2,389	0.05	7.79	0.04
Queensland arrowroot	1,431	0.03	4.69	0.03
Taro (*Amorphophallus*)	1,217	0.03	3.98	0.02
Swamp taro	823	0.02	2.68	0.01
Yam (*D. nummularia*)	478	0.01	1.55	0.01
Aerial yam (*D. bulbifera*)	467	0.01	1.51	0.01
Rice	407	0.01	5.82	0.03
Yam (*D. pentaphylla*)	37	0.00	0.13	0.00
Papua New Guinea	4,517,492	100.00	18,196.54	100.00

Source: Bourke and Vlassak (2004).

minor exceptions in parts of East Sepik and Western provinces. It has the widest distribution of any crop in PNG (Table A2.2.1).

Average sweet potato production for all rural villagers is calculated as 685 kg/person/year (Table 2.2.2). Production ranges from 1150 to 1200 kg/person/year in the five highlands provinces. Significant quantities per person are also produced in Bougainville, Morobe, Oro, West New Britain, New Ireland, Central, Madang, East New Britain, Milne Bay and Gulf provinces.

Banana is grown in all parts of PNG. Average banana production for all rural villagers is calculated as 105 kg/person/year. At a provincial level, production is greatest in Morobe, East New Britain, Central and Madang provinces. Production per person is greatest in East New Britain, Central, Morobe, Western and Madang provinces.

Cassava is an important crop in the lowlands. Production for all rural villagers is calculated as 65 kg/person/year. Production is greatest in Milne Bay Province, where it is commonly planted with sweet potato after taro and yam have been harvested, and in West New Britain. The highest production per person is also in West New Britain and Milne Bay provinces.

Taro (*Colocasia esculenta*) (*taro tru*) is grown in most locations in PNG, but often only as a supplementary crop. It was formerly the most important staple food in much of the lowlands, and was the most important food in the highlands before sweet potato was adopted there about 300 years ago (Figure 3.1.2). *Colocasia* taro production is greatest in Madang, East Sepik and Morobe provinces (Table A2.2.2). Production per person is greatest in West New Britain, Madang and Oro provinces. Average *Colocasia* taro production for all rural villagers is calculated as 55 kg/person/year.

Chinese taro total production and per person production is greatest in Morobe, Madang, East New Britain and West New Britain provinces. Average Chinese taro production for all rural villagers is calculated as 55 kg/person/year.

Yam is grown in all provinces and is an important staple food in some locations. Five species are grown, but three of these are unimportant as foods. The lesser yam (*Dioscorea esculenta*) (*mami* or *taitu*) accounts for 66% of yam production, and the greater yam (*D. alata*) (*yam tru*) for most of the rest. The greatest production of yam, especially *D. esculenta*, occurs in the hilly parts of East Sepik Province north of the Sepik River. Significant quantities are also produced in Madang and Milne Bay provinces. Production of yam per person is greatest in East Sepik and Milne Bay provinces. For the five yam species combined, average production for all rural villagers is calculated as 65 kg/person/year.

Coconut is grown in all coastal and many inland locations. The figures generated here are only for nuts consumed by people. Significant quantities of coconut are also fed to pigs or used to produce copra in some coastal locations. Average coconut production for all rural villagers is calculated as 40 kg/person/year.[3] The highest production of coconut for human consumption occurs in East Sepik, Madang, Milne Bay, Bougainville and East New Britain provinces. Production per person is also high in Manus, New Ireland, West New Britain and Sandaun provinces.

Sago is grown and eaten in most provinces. Average sago production for all rural villagers is calculated as 75 kg/person/year. The greatest production occurs in East Sepik, Sandaun, Western and Gulf provinces. Production per person is greatest in Manus, Western, Gulf, Sandaun and East Sepik provinces.

Irish potato is a relatively recent introduction and produced in lesser quantities than the older staples. Some growers produce commercial quantities of Irish potato for sale, but the figures generated here are only for subsistence consumption and produce sold from village gardens. Production is greatest at high-altitude locations in Enga Province. Production dropped greatly following an outbreak of potato late blight disease in 2003, and it is likely that production in 2006 was less than the estimates given here.

[3] Coconut and sago have a higher food energy content per unit weight (Table 2.2.1), so their average production figures were converted to sweet potato equivalent to be comparable with data on root crops and banana (Table 2.2.2).

Table 2.2.2 Estimated production of staple foods per rural person in 2000, by province (kg/person/year)

Province	1st staple		2nd staple		3rd staple		4th staple		5th staple		6th staple		7th staple		8th staple	
Western	Sago	450	Banana	140	Yam	90	Cassava	85	Sweet potato	65	Coconut	65				
Gulf	Sago	420	Sweet potato	220	Banana	115										
Central	Sweet potato	315	Banana	275	Cassava	125	Yam	115	Coconut	50						
Milne Bay	Cassava	275	Sweet potato	235	Yam	215	Banana	125	*Colocasia* taro	85	Coconut	80				
Oro	Sweet potato	500	*Colocasia* taro	110	Yam	110	Chinese taro	105	Cassava	100	Banana	95	Sago	55		
Southern Highlands	Sweet potato	1175														
Enga	Sweet potato	1200														
Western Highlands	Sweet potato	1150	Banana	80												
Simbu	Sweet potato	1210														
Eastern Highlands	Sweet potato	1195														
Morobe	Sweet potato	550	Banana	180	Chinese taro	165	Yam	75	*Colocasia* taro	65						
Madang	Sweet potato	250	Chinese taro	150	Yam	135	Banana	135	*Colocasia* taro	125	Coconut	75	Sago	65	Cassava	55
East Sepik	Sago	290	Yam	235	Banana	120	Coconut	95	Sweet potato	85	*Colocasia* taro	80				
Sandaun	Sago	375	Sweet potato	150	Banana	110	*Colocasia* taro	95	Coconut	75	Yam	55				
Manus	Sago	490	Cassava	165	Sweet potato	130	Coconut	90								
New Ireland	Sweet potato	375	Cassava	150	Yam	140	*Colocasia* taro	90	Banana	80	Coconut	85	Sago	65		
East New Britain	Banana	320	Sweet potato	245	Cassava	195	Chinese taro	180	Coconut	80	*Colocasia* taro	55				
West New Britain	Sweet potato	415	Cassava	365	Chinese taro	220	*Colocasia* taro	145	Banana	110	Coconut	75				
Bougainville	Sweet potato	555	Banana	105	Coconut	90	Chinese taro	75	Cassava	70						
All rural PNG	Sweet potato	685	Banana	105	Sago	75	Cassava	65	Yam	65	*Colocasia* taro	55	Chinese taro	55	Coconut	40

Source: Figures were generated by dividing the estimated production of each staple food in each province (Tables A2.2.1 and A2.2.2) by the provincial rural village population in 2000 (Table 1.1.1). So that a direct comparison can be made between sago and the other staple crops, production estimates for sago were converted to sweet potato equivalent by multiplying the food energy content per kilogram of sago divided by the food energy content of sweet potato. The same was done for coconut. Data for the five yam species have been combined. Crops where the production is less than 50 kg/person/year at the provincial level have been excluded. Figures have been rounded to the nearest 5 kg.

Rice for local consumption is grown in very small quantities in a number of provinces (see Section 2.5). Only in Bougainville Province did production exceed a few hundred tonnes per year in the mid 1990s, although rice production had virtually ceased there by 2002. Village plantings of rice have increased in a number of provinces since the late 1990s. However, total production in 2006 was probably less than 1000 tonnes per year, despite the increased interest in rice growing by some villagers and significant external support. Total rice production is still unlikely to exceed 0.1% of total staple food production in PNG.

Economic value of staple food production

These estimates of staple food crop production can be allocated a kina value by calculating the value of grain that would have to be imported to feed the population if all production of staple food crops ceased.

The quantity of *additional* rice that would have to be imported into PNG is 1.2 million tonnes. (Existing rice imports have averaged 152 000 tonnes per year since 1990 – see Section 2.7.) The retail value of this additional rice was K2850 million in 2004, indicating the great economic value of food production in PNG. The figure would be even larger if the value of vegetables, fruit, nuts, fish and meat was calculated.

Changes in production patterns

Estimates of production made in 2000 can be compared with estimates made in 1961–62 (Figure 2.2.1). The most striking change over this 40-year period has been the increased significance of sweet potato, cassava, Irish potato and Chinese taro. These are crops that were domesticated in the Americas and introduced into PNG over the past 300 years (in the case of sweet potato) or about 130 years ago (for the other crops).

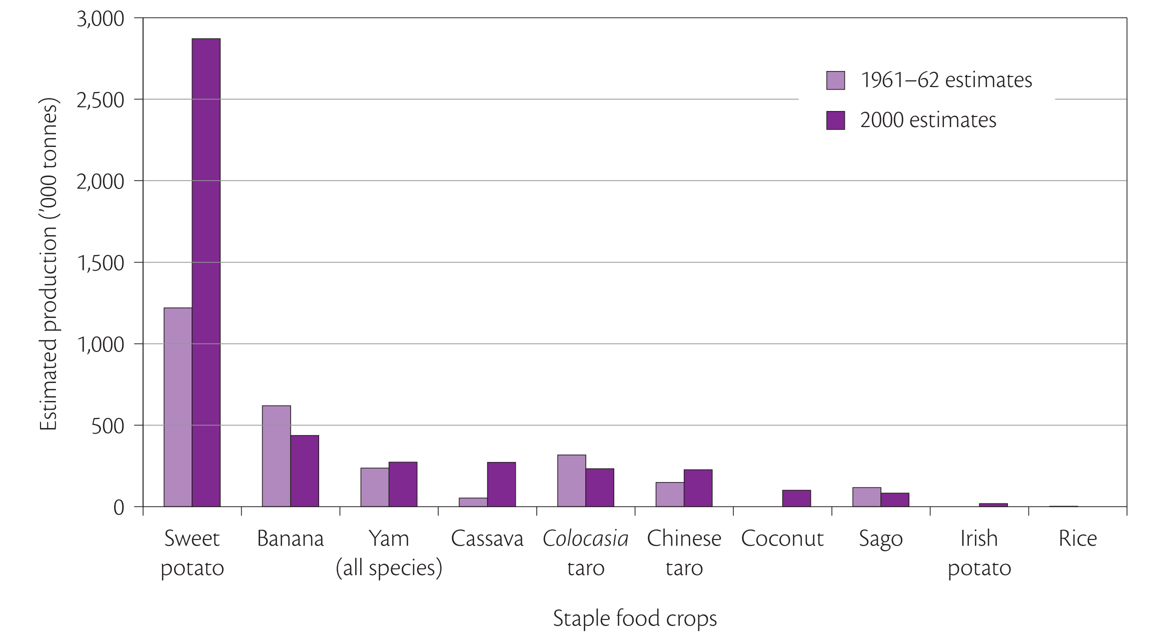

Figure 2.2.1 Comparison of the 1961–1962 and 2000 estimates of production by weight of ten staple food crops. **Note:** Coconut production was not estimated in 1961–62. Estimated Irish potato production in 1961–62 was negligible. Rice production was estimated as 3000 tonnes in 1961–62, and 407 tonnes in 2000. The 1961–62 figure for rice is unlikely to be accurate (see Section 2.5). Source: Bourke and Vlassak (2004).

In 1961 sweet potato provided an estimated 45% of the food energy from the staple food crops (excluding coconut). This proportion had grown to 66% by 2000 (Figure 2.2.2). Similarly, the food energy from cassava increased from 2% to 6%. Irish potato production was negligible 40 years ago, but has increased rapidly since then. Production of Chinese taro increased rapidly in the 1960s and 1970s but, from the 1980s onwards, production decreased in many locations because of a disease problem, probably a root rot. Hence the relative contribution of Chinese taro to food energy in 2000 was about the same as it was in 1961–62.

In contrast to crops that originated in the Americas, the proportion of total food energy provided by the food crops that originate in the Asia–Pacific region has declined since 1961. This is the situation for banana, yam, *Colocasia* taro and sago. The estimated total production of these crops in 2000 was similar to the estimates 40 years earlier, but their proportional contribution to total production has dropped relative to that of the crops from the Americas, especially of sweet potato and cassava (Figure 2.2.3).

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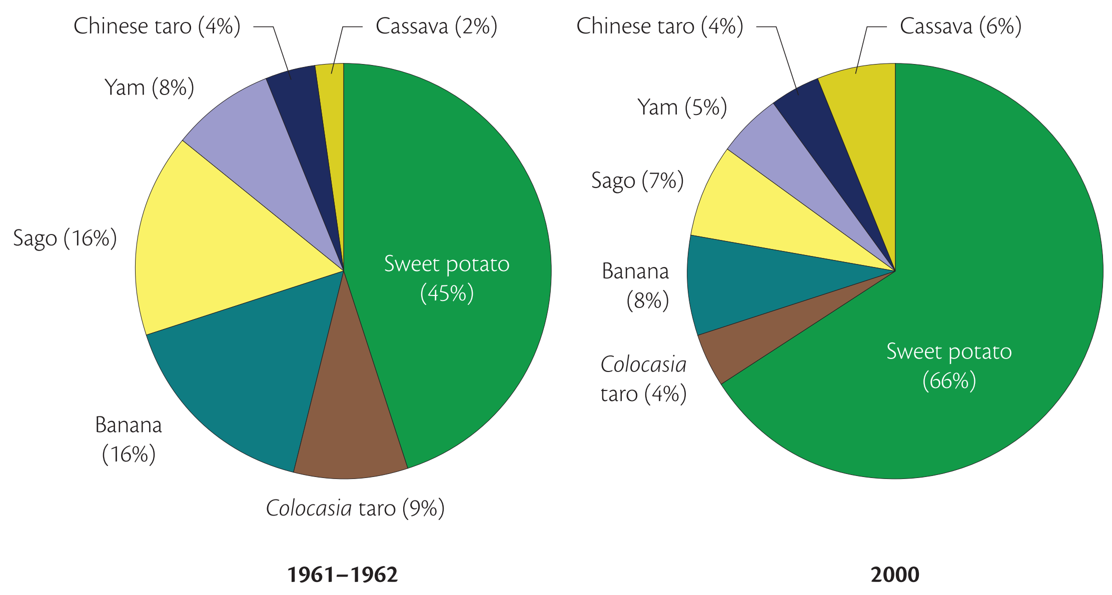

Figure 2.2.2 Estimated production of food energy of staple food crops: Survey of Indigenous Agriculture, 1961–1962 and Mapping Agricultural Systems of PNG Project, 2000. **Note:** Rice was estimated as 0.4% of food energy of the staple food crops in 1961–62, and as 0.03% in 2000. Sources: Walters (1963); Bourke and Vlassak (2004).

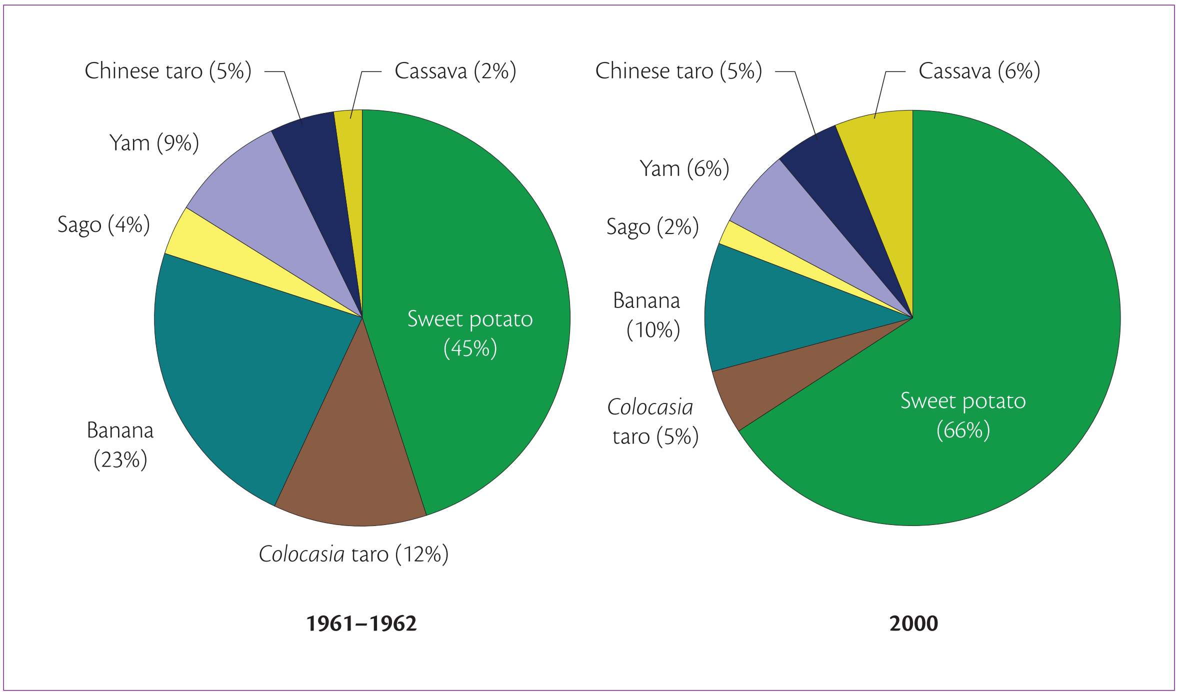

Figure 2.2.3 Estimated production by weight of staple food crops: Survey of Indigenous Agriculture, 1961–1962 and Mapping Agricultural Systems of PNG Project, 2000. **Note:** Rice was estimated as 0.1% of production by weight of staple food crops in 1961–62, and as 0.01% in 2000. Coconut production was not estimated in 1961–62. Coconut contributed an estimated 2.2% of food produced in 2000, but has been excluded from these figures so that the two datasets can be compared. Sources: Walters (1963); Bourke and Vlassak (2004).

2.3 Genetic diversity of food crops

Papua New Guinean villagers pay particular attention to variation among cultivated crops. They try out new variants and retain useful ones which, in suitable conditions, become established as cultivated varieties (cultivars). This is a continuous process and enhances crop genetic diversity. It has been going on in PNG for thousands of years, providing insurance against changing conditions such as drought or new diseases, and adapting plants to new environments. Both indigenous crops such as taro and banana, and introduced ones such as sweet potato, are managed in this way.

Most crops in PNG are propagated vegetatively, that is, by planting suckers, shoots or cuttings. This is known as asexual propagation, and only requires one parent plant. New plants grown by this method are usually identical to the parent plant. Sometimes, however, changes develop in parts of a plant because of abnormal division of somatic (body) cells. This process of somatic mutation is random and often injurious to the new plant. If the plant survives, human judgements about the usefulness or otherwise of the new form will then determine whether the new variant becomes an established variety. If the mutation occurs in buds, suckers or other plant parts that can be propagated, human intervention may result in the establishment of a new cultivar. Variant plants are not necessarily useful, but innovative villagers will try them out. Visible changes such as a new leaf shape or stem colour might be valued for associated desirable fruit or root characteristics, or might be retained just because they look attractive.

Some PNG crops that are planted vegetatively are not completely sterile, and can interbreed with wild forms. For example, some of PNG's many banana cultivars produce occasional seeds and/or pollen. Cross-fertilisation with wild banana plants may produce edible forms with novel characteristics. These may be noticed and tried out by further propagation. This has happened in the past, and has produced hybrid bananas unique to PNG. Cultivars of sweet potato, sago, *aibika* and *marita* pandanus may also have arisen from flowering and seeds, as well as from somatic mutation.

Variation is common in sexually propagated plants. Some PNG crops, such as breadfruit, coconut and other tree crops, grow from seed. Seedlings may or may not have the characteristics of the parent plant, depending on whether the breeding mechanism involves cross-pollination (the transfer of pollen from another plant of the same species) or self-pollination. Breadfruit and coconut are mainly cross-pollinated, and the resulting seedlings are genetically as diverse as the parent population. However, villagers may select and retain or transplant seedlings with desirable characteristics. If a particular trend of selection continues through enough breeding cycles, the characteristics of the population may be progressively altered. A process like this probably produced the large-fruited forms of tree crops like *galip* and *okari*. Breadfruit trees with particularly desirable characteristics are reproduced from rootstocks,[1] to give an identical new tree. Desirable new forms of plants are commonly given to people in other villages and so spread quickly away from their origins.

It is common throughout PNG to find many named cultivars of staples and supplementary fruit, vegetables and nut crops, and villagers are often well aware of prized local cultivars and their origins. Despite this diversity, there have been few studies of food crop variation, and even fewer of how villagers manage it. Conserving the genetic diversity of PNG's crops has so far been largely in the hands of PNG's villagers. In a modernising world, they will need improved institutional support, which cannot be provided without more studies of cultivated varieties and of local management practices.

1 Rootstocking involves taking a short piece of root from a tree and growing it into a tree seedling with its own roots and leaves.

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2.4 Food crop yields

Yield is an important measure used to compare production between different crops or between different varieties. Yield is also used to compare changes in a crop over time or under different cultivation conditions. Knowing crop yield helps development workers understand why villagers grow certain crops or adopt certain practices, although other factors influence villagers' decisions, including taste and cultural values.

A lot of information exists about food crop yields in PNG, with most of the data from research station experiments. The extensive number of publications consulted (see sources) show that information on crop performance is widely dispersed throughout the literature, some of which is difficult to locate. A summary of these data is presented in tables in this section. However, a complete review of published and unpublished trial data on food crop yields – experimental and village plantings – is beyond the scope of this book.

The four primary measures of yield are:

- **Weight of economic product per unit area.** The most common way to present yield data – the usable portions of tubers, grain or fruit from plants growing within a known area – is weight per unit area. For field crops it is usual to express yields as kilograms per hectare (kg/ha) or tonnes per hectare (t/ha).
- **Weight of economic product per plant.** In the case of tree crops, it is common for yield to be expressed as weight per tree (kg/tree), in which case the weight of fruit from a known number of trees is divided by the number of trees to give an average yield per tree.
- **Weight of economic product per unit area per unit time.** This is a useful measure for some purposes, especially for comparing yields in different environments, where crops may take different times to mature. A hypothetical example of such a comparison is: sweet potato yields are 13 t/ha over 18 weeks at sea level and 25 t/ha over 35 weeks at 1800 m altitude. In this case, the yield per unit time is 0.7 t/ha per week in both environments.
- **Weight of economic product per unit labour input to grow the crop.** Yields per unit of labour estimate how much work is required to produce a crop. This measure of yield is particularly important when looking at human–crop interactions. For example, weeding, pruning and draining will double the yield of coffee per unit area, but labour inputs needed to achieve the higher yield are *more than double* those used by most villagers. The additional labour will significantly reduce the yield per hour worked. This explains why recommended techniques are not adopted by most villagers (see Section 5.20). It is difficult to collect good quality labour data, so this important measure is rarely used.

Yield data

Yield data for PNG comes from two main sources: research stations or experiments by researchers on village land, and village gardens. Experimental data are collected when a researcher grows a crop under controlled conditions, usually on a research station, and then weighs the harvest. Considerable amounts of experimental data are available for rice, sweet potato, sugar cane, corn (maize), peanut, Irish potato, soya bean, cabbage, tomato, winged bean and taro, and for the export cash crops cocoa, coffee, coconut and oil palm. These data come mainly from agricultural research stations (Aiyura, Bubia, Dami, Keravat, Kuk, Laloki and Tambul (see map on page xix)). Little data exists for other food crops such as banana or sago, or for the minor cash crops balsa, cardamom, pyrethrum, rubber, tea and vanilla. Much experimental data is not published and so is not accessible.

Village yield data comes from measuring production from village gardens that were planted using village methods without interference from the researcher. Some village yield data are available for sweet potato and, to a lesser extent, for taro, yam, winged bean and Arabica coffee. For most other food crops, few yield records have been made from village plantings.

Important distinctions must be made between experimental and village yield data and the type of data must always be determined before comparisons are made. It is difficult to measure yield from village-controlled plantings because most crops are grown in mixed plantings. Meaningful yield data per unit area can only be calculated where a reasonably large number of plants are planted together in a plot. Thus one can calculate yield per hectare of sweet potato, taro, yam, cocoa or coffee in PNG, as these crops are often planted as a single species plot. However, meaningful yield per unit area cannot be calculated where plants are grown interplanted with other species. This is how most vegetables and minor staple foods are planted in village gardens.

Most crops in PNG are harvested progressively over some months (yam is an exception) and collecting yield data under these circumstances is difficult. Weighing a single harvest does not properly reflect village production. Village trees are rarely planted together, but are scattered through gardens and fallow land. Thus yield from fruit and nut trees is best expressed as yield per tree per year. Another difficulty is that experimental plots, with regular weeding and maintenance, may produce artificially high yields because the crop management does not accurately reflect village practices.

The best yields of root crops from PNG are as good as, or better than, the best yields reported in other tropical locations, although not as high as those in many subtropical locations where soil fertility is maintained by fertiliser and improved varieties are grown. Yields of subtropical and temperate-climate fruit and vegetables tend to be lower in PNG than in subtropical and temperate-climate locations. Yield data on export cash crops are not reviewed in this section. (See Part 5 for production and export data for cash crops.)

Some sources of yield data are unreliable and care should be taken in their use. The Food and Agriculture Organization of the United Nations (FAO) publishes yield data for food crops that purports to be for PNG, but these data are not based on any recordings in PNG. FAO also presents yield data for export tree crops that appear to be reasonably accurate, but cannot be used to interpret trends over time. Information on the area planted each year is needed to calculate changes in yield over time. The only PNG crops that have reliable long-term data on the area planted each year are oil palm and commercial sugar cane.

Crop yields appear to be changing in some locations. On small islands in particular, crop yields are now very low because population increases have led to intensification of land use, resulting in reduced soil fertility (see Table 1.3.1 and Sections 3.6 and 3.7). In these places, food crops that require high levels of soil fertility, such as taro, yam and corn, cannot be grown, and less demanding crops such as cassava, sweet potato and banana yield poorly. Elsewhere, villagers report that declines in crop yield and the inability to grow certain food crops have taken place over the past 30–50 years.

Staple food crops

A moderate amount of information is available for yields of staple food crops under village conditions, particularly for sweet potato, but much more data is available from experiments. Many of the datasets have very wide ranges, which makes it difficult to generalise. It is sometimes necessary to use a single figure, for example the average yields for the lowlands and highlands (Table 2.4.1). (These are the same figures that were used to generate estimates of staple food production in PNG – see Section 2.2.) These are the best estimates for yields under village conditions but much variation around these averages has been recorded and care must be taken when interpreting results from their use.

Banana

Published data on village banana yields are available from only two studies (Table 2.4.2). The study on banana production in the village north of Nomad in Western Province is one of the most detailed studies of lowland village production for any food crop. Banana yields in the Madang and Nomad areas are similar at 6–8 t/ha (4–5 t/ha edible portion).

Banana yield data comes from four experimental plantings in three lowland provinces. These yields vary between trials and locations, but are generally higher than for village production. Mean fruit bunch weight ranged from 9 kg to 27 kg. Mean bunch yield was in the range 5–15 t/ha/year, although the bearing period for yield recording varied between the different studies. The edible portion of diploid varieties was 60–66% in the two village studies and this was higher than that for triploid Cavendish varieties at Keravat (47%) or mixed triploid varieties in villages near Madang (57%).[1]

[1] Diploid varieties have two sets of chromosomes; triploids have three sets. Triploid banana varieties are usually larger plants and produce larger bunches. Many triploid varieties persist for many years after planting, especially if weeds are removed.

Cassava

No yield data exist for cassava under village conditions. Where soil fertility is high and the growing period is long, for example in the Wahgi Valley, tuber yield is very high and individual tubers have been recorded as heavy as 12 kg. In contrast, where soil fertility has been reduced by long periods of cropping in the lowlands because of population

Table 2.4.1 Average crop yield used for calculating staple food crop production (t/ha)[a]

Crop	Lowlands (0–1200 m)	Highlands (1200–1800 m)
Banana	12	9
Cassava	22	16
Irish potato	–	14
Queensland arrowroot	10	–
Rice	2	–
Sweet potato	13	15
Taro (*Alocasia*)	8	–
Taro (*Amorphophallus*)	6	–
Taro (*Colocasia*)	8	10
Chinese taro	14	11
Swamp taro	6	–
Aerial yam	13	13
Greater yam	13	11
Lesser yam	15	–
Yam (*Dioscorea nummularia*)	13	–
Yam (*Dioscorea pentaphylla*)	9	–

[a] These figures were used with other data to calculate production of staple food crops at the level of agricultural system, and then aggregated to provincial and national level (see Section 2.2). The figures are best estimates only and are more precise for the better-known species, such as sweet potato, *Colocasia* taro, lesser yam and cassava, than for the minor species.

Figures were assembled from published and unpublished records for village production. Where there were few or no village recordings, a figure of 75% of average experimental yield was used. For some of the minor yam and taro species, yields were taken as the same as the better-known species.

Source: Bourke and Vlassak (2004:19).

pressure, for example on some small islands, tubers may weigh only 100–300 g and yield per plant is only 1–2 kg.

A moderate amount of experimental research has been conducted on cassava and most results have been published. Experimental yields are often high and tuber yields up to 45 t/ha are common (Table 2.4.3). In one variety trial conducted at Laloki in 1985–86, six varieties yielded in the range 76–124 t/ha, with a mean tuber yield of 101 t/ha. Crops may be harvested from 10 months after planting. These experimental yields are mainly for crops 12–14 months old.

Irish potato

There are no published data on yield of Irish potato under village subsistence or commercial field conditions. Until the mid 1980s, Irish potato was rarely grown in single species stands and villagers interplanted it with sweet potato, so it was not possible to gather reliable village yield.

Many experiments have been done on Irish potato, particularly in the highlands provinces. There is less information from lowland and intermediate altitudes. Experimental yields have been recorded as low as 1 t/ha and as high as 60 t/ha. Yields in the highlands are typically in the range 10–35 t/ha (Table 2.4.3). As the time to maturity is about 100 days at 1600–1800 m altitude, productivity per unit time is very high for Irish potato, especially when crops are

Table 2.4.2 Village and experimental yield of banana

Location	Bunches (per hectare)	Mean bunch weight (kg)	Bunch yield (t/ha)	Yield edible portion (t/ha)	Source
Village yield					
Amele[a]	1032	5.4	5.6	3.7	King et al. (1989)
Nomad[b]	1313	5.7	7.5	4.5	Dwyer and Minnegal (1993)
Experimental yield					
Lejo[c]	510	9–27	4.6–13.8	–	Heenan (1973)
Keravat[d]	–	–	9.9	–	Gallasch (1980)
Keravat[e]	1240	12	14.9	7.0	Tarepe and Bourke (1982)
Laloki[f]	–	15.3	–	–	Kambuou (2005)

[a] The Amele area is south-west of Madang town. About 90% of bananas in food gardens are diploid. The edible proportion of diploid varieties was 67% and for triploid varieties was 57%. Mean bunch weight and yield of edible portion are based on diploid varieties. Banana is only one component of food gardens, so yield per hectare is less than from plots consisting of mainly banana plants.

[b] In villages north of Nomad, Western Province, diploid bananas are grown in mainly single-species stands. Bunches were available for eating 8–20 months after planting.

[c] Banana yields were recorded over a 16-month period for Giant Cavendish, Dwarf Cavendish and Tui varieties at Lejo Experiment Station in Oro Province. Yield recording commenced two years after planting. Bunch weight increased from 9 kg at two years to about 27 kg by 40 months after planting. The bunch yield given here is derived by multiplying the mean weights by the original planting density (510 plants/ha).

[d] The Yawa variety was planted under coconuts at Keravat, East New Britain Province. The bunch yield of 9.9 t/ha was recorded for the first 32 months of the trial. It takes about a year for this variety of banana to bear, hence the yield is equivalent to 9.9 t/ha over 20 bearing months.

[e] Experimental yields in the early to mid 1970s from five blocks of mature Giant Cavendish banana ranged from 9 to 20 tonnes of bunch per hectare per year, with a mean of 14.9 t/ha/year.

[f] In an irrigated trial at Laloki near Port Moresby, six common varieties and eight varieties derived from breeding lines were evaluated. Mean bunch weight ranged from 1.5 to 37.6 kg/bunch, with a mean of 15.3 kg/bunch.

Table 2.4.3 Village and experimental yield of selected root crops

Crop	Edible part	Village yield range (t/ha)	Typical experimental yield range (t/ha)	Maximum experimental yield (t/ha)	Maximum weight for an individual 'root' (kg)	Source[a]
Cassava	tuber	–	10–45	124.3	11.9	Grant et al. (2004); King (1986b, 1988)
Irish potato	tuber	–	10–35	61.2	1.8	Pitt and Yandanai (1988); Wiles (2001b)
Sweet potato	tuber	2–50	5–30	71.2	9.5	Bourke (1985, 2005)
Taro (*Alocasia*)	corm	–	–	–	40.0	
Taro (*Colocasia*)	corm	3–38	4–12	44.3	10.0	Bayliss-Smith (1982); Gendua et al. (2001); Singh et al. (2006)
Chinese taro	cormel	–	8–25	38.0	3.7	
Swamp taro	corm	8–12	17–48	48.1	15.0	Bourke and Betitis (2003)
Winged bean	tuber	6–12	1–3	14.8	–	
Greater yam	tuber	10–16	5–30	42.2	63.6	King (1986a, 1986b, 1989); Quin (1984); Risimeri (2001)
Lesser yam	tuber	10–21	10–40	95.6	11.5	Allen (1982); Johnston and Onwueme (1999); King (1986a, 1986b, 1989); Quin (1984); Risimeri (2001)
Yam (*Dioscorea rotundata*)	tuber	–	10–45	61.0	–	Risimeri et al. (2001)

[a] This table was adapted from Bourke (1982:56), where the original sources are given. The sources listed here provide supplementary information.

fertilised. Because there are big differences in yield between varieties and Irish potato is responsive to fertiliser, there are often large differences in yield even within a single trial. The only published yield data from the lowlands come from Keravat where different varieties yielded from 0.1 t/ha to 17 t/ha. On the Lelet Plateau on New Ireland Province at 900 m altitude, yields of assorted varieties were in the range 5–37 t/ha.

Sago

Published sago yields are available for 14 locations in PNG (Table 2.4.4). The recorded yield per palm varies widely, even within one location, with a range of 30 kg to more than 500 kg of dry starch per palm and a mean of 180 kg per palm. A feasibility study for production of sago flour in East Sepik Province by Toyo Menka Kaisha Ltd in 1972 recorded an average of 168 kg of dry starch per palm. Planting density is reported as 280–310 palms per hectare. A harvesting rate from planted or wild stands has been reported from five locations, with a range of 7 to 42 logs per year. Combining this harvest density with an average yield of 168 kg dry starch per palm suggests yields of dry starch of 1–7 t/ha/year. This contains the same food energy as between 4 and 27 tonnes of sweet potato. This is the potential yield from current stands of sago where extraction is done manually.

The potential yield from a sago plantation is likely to be much higher, and has been calculated as 25 tonnes of dry starch/ha/year (based on a harvest of 138 logs/ha/year and 185 kg starch/palm). Yields can be increased from existing stands by thinning out palms, removing other tree species and extracting starch mechanically. The long period from planting to maturity (12–15 years) is a consideration in planting sago in a managed plantation, although some varieties mature in less than 10 years.

The quantity of dry starch generated per labour input has been recorded at 10 locations on the PNG mainland at 2.0–3.7 kg/hour. A lower return of 0.5–0.8 kg was reported from south-west Bougainville where a different species of sago (*Metroxylon salomonense*) is used.

Table 2.4.4 Village starch yield per palm and per labour input from sago palms in various locations

Location	Starch yield (dry weight)	
	Per palm (kg/palm)	Per labour input (kg/hour)
Fly River, Western Province	79–159	–
Oriomo Plateau, Western Province	29–104	2.0
Ok Tedi area, Western Province	–	1.9
Kikori area, Gulf Province	–	2.6
Purari River delta, Gulf Province	–	3.5
Middle Sepik River, East Sepik Province	–	3.7
East Sepik/Enga provinces border area	–	3.1
Karawari River, East Sepik Province	230	2.9
Ambunti area, East Sepik Province	28–206	2.2
Ambunti area, East Sepik Province	–	2.0
Angoram area, East Sepik Province	150–400	–
Maprik, East Sepik Province	–	2.0
Nuku area, Sandaun Province	70–513	–
South-west Bougainville Island	–	0.5–0.8

Sources: Adapted from Townsend (1982:14–15) and Sowei (2006), who both give original sources.

Sugar cane

No yield data are available for village sugar cane, even though production throughout PNG is substantial (variously estimated as 190 000 to 440 000 tonnes of cane per year). The sugar content of village cane is almost certainly lower than that of commercial production because village sugar cane has been selected for high juice content rather than high sugar content.

Sugar is produced commercially by Ramu Agri-Industries Ltd in the Ramu Valley, Madang Province (see Section 5.10). Cane yields there vary between 50 t/ha and 90 t/ha, and are typically around 55–60 t/ha. The sugar content of the cane is about 9%, so 55–60 tonnes of cane produces 5–6 tonnes of sugar per hectare. The yield achieved in any year is influenced by the incidence of pests and diseases.

Sweet potato

It is difficult to measure sweet potato yields under village conditions because of the progressive harvesting method that villagers use. It is possible to record the weight of all tubers from a plot at one time, but this is not how villagers harvest and figures are likely to underestimate the total yield.

By the mid 1980s, village yields were available for about 30 PNG locations, mostly in the highlands. The range of recorded yields was 2–50 t/ha. However, some of the earlier recordings are unreliable. The range for the more reliable figures in the highlands was 5–31 t/ha. Little information on village sweet potato has been published since then and the more recent figures do not extend the range.

A large number of experimental yields have been recorded for sweet potato, with much of the data unpublished. Experimental yields are typically in the range 5–30 t/ha, but yields of up to 71 t/ha have been recorded (Table 2.4.3). Plantings in larger blocks have also given high yields, for example, the average yield in a fertiliser trial near Goroka was 70 t/ha for a 34-week crop. Yields are often higher in the highlands than in the lowlands, but the ranges cited above have been recorded in both environments. Experimental yields of 20–30 t/ha are common in the highlands and a lower range of 15–20 t/ha is more typical in the lowlands. The growing period in the lowlands is 3–5 months.[2] It is 5–8 months at 1500–2000 m altitude and longer at higher altitudes.

Sweet potato yields can vary greatly, even between different parts of the same garden. Yields often vary considerably from crop to crop, even under the most rigorous experimental conditions. Some of this variation is probably associated with minor variation in experimental technique. For example, it is known that planting different lengths of vine can influence yield. It is often not obvious why sweet potato yield varies so much from crop to crop, but sweet potato is sensitive to soil moisture conditions and nitrogen levels.

Colocasia taro

Colocasia taro yields are low compared with the other root crops. They have declined over the past 50 years probably because of reductions in soil fertility associated with more intensive land use and increased virus, fungus and insect problems. Village yields have been recorded as high as 38 t/ha under irrigated conditions, which are not common in PNG (Table 2.4.3). The highest subsistence yield recorded for non-irrigated conditions is 15 t/ha. The crop matures in 6–9 months in the lowlands but requires more than a year in the highlands. It is relatively easy to estimate taro yields in village plots based on the weight of a sample of corms because the harvest density is typically about 10 000 plants/ha and there is only one main corm per plant. If mean corm weight is 0.8 kg, the mean yield is about 8 t/ha.

Yields under experimental conditions are typically in the range 4–12 t/ha, with the recorded range from complete crop failure (0 t/ha) to 44 t/ha. A valuable review of yield and labour inputs under village and experimental conditions up to 1980 is given by Bayliss-Smith (1982). He recorded yield at Baisu Corrective Institution near Mount Hagen at an average 17 t/ha, which demonstrates that yields of taro on highly fertile soil in the highlands can be higher than in the lowlands, although the growing period is longer.

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2 It is commonly stated that sweet potato matures in three months in PNG, but three months (90 days) is the minimum period to maturity in the lowlands. Yield commonly increases after 90 days until 150 days after planting in the lowlands.

Chinese taro

No yield data exist for village plantings of Chinese taro. A few experiments have been conducted at Keravat where yields were usually in the range 8–25 t/ha for a 12-month crop. Chinese taro is usually harvested from about 10 months after planting and can continue for some years, although harvesting is reduced after about two years from planting.

Swamp taro

On Mortlock Island east of Bougainville, swamp taro yields were estimated as 8–12 t/ha/year. Mean corm weight was about 8 kg and time to maturity was said by villagers to be 3–6 years, but larger corms are produced if harvesting is delayed.

The only published experimental yield data are from two plantings at Keravat which yielded 48.1 t/ha after 7.5 years and 16.7 t/ha after 2 years. This is equivalent to 6–8 t/ha/year, similar to the lower estimate from village plantings on Mortlock Island. The largest individual corm in the experimental plantings weighed 15 kg.

Taro (*Alocasia* and *Amorphophallus*)

There are no village or experimental yield data for *Alocasia* or *Amorphophallus* taro, except for some recordings on the weight of individual corms of *Alocasia* in village plantings on the Gazelle Peninsula, East New Britain Province. The range of weight recorded was 8.5–40.0 kg per corm. In both species, the edible corm does not mature and can be harvested as needed, sometimes when a plant has been growing for some years.

Yam

Some yam yield data have been recorded from villages in East Sepik and Central provinces. The average of all village recordings for greater yam (*Dioscorea alata*) is about 13 t/ha and for lesser yam (*D. esculenta*) is about 15 t/ha (Table 2.4.3). In one study of 12 villages in the lowlands of Central Province, greater yam tubers were larger on average (365 g) than lesser yam (220 g), but greater yam had fewer tubers per plant (2.9 compared with 9.3), so the yield per area was higher for *D. esculenta* (20.5 t/ha) than for *D. alata* (10.5 t/ha).

There are more experimental data for lesser yam than for greater yam. Like the village data, experimental yields of lesser yam (10–40 t/ha) are usually higher than those for greater yam (5–30 t/ha), with yields as high as 95 t/ha for lesser yam and 42 t/ha for greater yam. Greater yam matures at around 6–7 months and lesser yam at around 6–9 months.

White yam (*D. rotundata*) is an African species introduced to PNG in 1986 and increasing in popularity. Published information on crop performance is limited. In an evaluation at Bubia near Lae, yields of 61 t/ha were recorded.

Grains and grain legumes

Much research has been conducted in PNG on grains and grain legumes, particularly rice. A comprehensive review of published and unpublished literature is not attempted here, but an indication of the yield ranges is given. Almost all yield data are from experiments, although some data are available from commercial maize, commercial sorghum and village rice production in the Markham Valley, Morobe Province.

Corn (maize)

No yield data exist for village plantings. Corn has been grown commercially for more than 30 years in the Markham and Ramu valleys, where the yields were reported as 2.5 t/ha in 1976.

Yields of up to 9.2 t/ha have been reported from small experimental plots of imported varieties but experimental yields are commonly in the range 2–6 t/ha (Table 2.4.5). The best yields of corn in PNG are lower than those obtained in subtropical and temperate climates – in Australia and the United States, for example. Hybrids generally give higher yield than open-pollinated types, but the latter are more suitable for village conditions because the seed can be replanted. Seed from village plantings often gives a low yield when grown under experimental conditions. This is because villagers select seed for replanting from a small number of cobs, which results in 'inbreeding depression', where there is insufficient genetic diversity to obtain good yields. A simple way to increase village corn yield is to select seed for replanting from a larger number of cobs from all over the garden.

Peanut

In the early 1960s average village peanut yields in the lowlands were estimated as 1.2 t/ha of pods (nut-in-shell) (about 0.8 t/ha of kernel). A 2004 National Agricultural Research Institute (NARI) survey reported village pod yields as 0.6 t/ha in Eastern Highlands Province and 1.5 t/ha in the Wahgi Valley of Western Highlands Province. Average village pod yields in the upper Markham Valley in 2005 were reported as 0.9–2.0 t/ha, with a maturity time of 105 days or more.

Experimental peanut yields at Aiyura, Keravat and in the Markham Valley are typically 1–4 t/ha, with pod yields of up to 7.6 t/ha reported (Table 2.4.5). In 2003–2005, a number of varieties introduced from India were evaluated in the upper Markham Valley and at Aiyura. Pod yields of the best varieties in the Markham Valley were 4–5 t/ha and the best of the introduced varieties outyielded local varieties. Short-term varieties matured in up to 90 days and medium-term varieties required more than 120 days. At Aiyura, the best varieties yielded 2–5 t/ha of pods; local varieties yielded 0.5–2.0 t/ha. Short-term varieties took 126–134 days to mature at Aiyura and medium-term ones required 150–164 days.

Table 2.4.5 Experimental yield of six grain and food legume crops (t/ha)

Crop	Location	Experimental yield		Source
		Total range	Typical range	
Corn	Aiyura	1.4–6.0	2–4	Akus (1983)
Corn	Keravat	0.5–7.2	2–5	Bourke (1976b)
Corn	Laloki, Tanubada	0.5–7.6	3–6	King and Bull (1989)
Corn	Markham Valley	0.0–9.2	3–6	King (1987); Vance (1976, 1987a)
Peanut	Aiyura	0.1–7.6	1–4	Rachaputi et al. (2006)
Peanut	Keravat	0.3–3.5	1–3	Bourke (1977); Gallasch (1980)
Peanut[a]	Markham Valley	0.3–4.2	1–2	Vance (1987b)
Peanut	Upper Markham Valley	1.1–5.9	1–4	Rachaputi et al. (2006)
Rice[b]	Five provinces[c]	0.4–8.5	2–5	Wohuinangu and Joo (1982)
Rice	Markham Valley	2.9–10.5	5–8	Lin (1993); Sajjad (1996)
Sorghum	Aiyura	1.6–3.7	2–3	Kimber (1977b)
Sorghum	Keravat	0.9–3.6	1–3	Bourke (1977)
Sorghum	Markham Valley	0.0–11.0	1–5	Vance (1981); Vance and Li (1971)
Soya bean	Aiyura, Goroka, Kuk	–	1–2	Kimber (1977a)
Soya bean	Markham and Ramu valleys	0.2–3.3	1–3	Kambuou (1992)
Wheat	Aiyura	0.0–2.5	0.5–1.5	Kimber (1977b)

[a] Peanut yields reported by Vance are generally expressed as kernel yield, while other authors report pod yield. Kernels constitute about 65% of the weight of pods.

[b] Rice yields are for paddy rice. The recovery of white rice from paddy rice after milling is about 60%, so multiply these figures by 0.6 to convert them to white rice equivalent.

[c] Wohuinangu and Joo (1982) give an overview of a large body of research on rice conducted between 1965 and 1980 in Morobe (Bubia, Markham Valley), Central (Bereina), Milne Bay, East Sepik (Maprik) and Madang provinces.

Rice

Yields of village rice in the Markham Valley are reported as 1.3 t/ha where there is no elaborate land preparation or added fertiliser.[3] Village yields in the Dreikikir area of East Sepik Province were recorded as 1.5 t/ha (range 0.4–2.8 t/ha). Under broadacre farming conditions in the upper Markham and Ramu valleys, commercial yields were reported as about 2 t/ha in the late 1970s. Upland village rice was reported to yield an average of 2–3 t/ha and a maximum of 5 t/ha in the Markham Valley in the 1990s. The highest reported yield from a village planting is 11.7 t/ha. Small plots grown by 50 households in one village in the Markham Valley growing about 10 ha yielded 4 t/ha under high input conditions.

Rice is the most-researched crop in PNG (Table 2.5.1) and a great deal of experimental yield data are available. Experimental yields of more than 10 t/ha of paddy have been reported in the Markham Valley and experimental yields are typically in the range 2–5 t/ha (Table 2.4.5). Yields of irrigated rice are generally higher than those from upland rice. For example, in the 1980s the recommended variety (NG6637) was reported to yield 3.7 t/ha under upland conditions and 5.2 t/ha under irrigated conditions.

Sorghum

Sorghum was grown commercially in the Markham Valley in the 1970s by expatriate farmers where 300–500 ha were sown each year. It is rarely grown in PNG now. Experimental yields are usually in the range 1–5 t/ha, and up to 11 t/ha in the Markham Valley, but yields were lower at Aiyura and Keravat where less experimental work was conducted.

Soya bean

Soya bean is rarely grown in PNG. A reasonably large amount of research has been conducted on soya bean, mainly in the Markham and Ramu valleys and at various highland locations. Average experimental yields in the lower Markham Valley were reported as 2.5 t/ha and in the drier areas of Gusap in the Ramu Valley and the upper Markham Valley as about 1.2 t/ha. Experimental yields of up to 3.3 t/ha have been recorded.

[3] All figures are for paddy rice. To convert this to white rice equivalent, multiply by 0.6.

Wheat

Wheat is not grown commercially in PNG. Some experimental work was conducted in the 1970s, when yields of up to 2.5 t/ha were recorded. It was concluded that rainfall in the PNG highlands was too high for successful wheat production. Since about 1999, some experimental work has been conducted by Chinese and later NARI researchers at Kandep in Enga Province, but yield data have not been made available.

Minor pulse crops

A limited number of yield records have been published for seven minor food legumes (Table 2.4.6).

Table 2.4.6 Experimental yield of seven minor food legume crops at various locations (kg/ha)

Crop	Port Moresby[a]	Bubia and Markham Valley[b]	
	Mean	Range	Mean
Bean, adzuki	–	1200–1600	1300
Bean, common	700	–	–
Bean, jack	1600	–	–
Bean, mung	1500	100–1300	600
Bean, rice	900	–	–
Cowpea	900	–	–
Pigeon pea	800	0–6100	1700

[a] The source for the Port Moresby data is Khan et al. (1976). The data are based on a limited number of experiments and observations.

[b] The source for the data from Bubia (near Lae), Gusap Downs and Leron Plains in the Markham Valley is Kambuou (1984). Kambuou (1982) gives average experimental yields for mung bean as 800 kg/ha and for adzuki bean as 1500 kg/ha.

Vegetables

No yield information exists for traditional (pre-1870) or introduced (post-1870) vegetables grown under village conditions.

A limited amount of published data exist from experiments on the traditional vegetables *aibika*, highland *pitpit*, rungia and especially winged bean (Table 2.4.7). Two trials were conducted at Aiyura which evaluated 12 species of traditional and 13 species of introduced vegetables (Table 2.4.8). Some trials have been conducted in villages, but they were managed by researchers.

At least 237 agronomic field trials were conducted on 30 species of introduced vegetables between 1928 and 1978 (Table 2.5.1). Cabbage and tomato have been well studied (over 40 trials on each up to 1978), but many trials were also conducted on cucumber, onion, lettuce, cauliflower, carrot and capsicum.[4] Many more trials on introduced vegetables have been conducted since 1978. While some recommendations have been published, details of most trial outcomes remain unpublished.

4 Cucumber is a traditional vegetable in PNG, but is considered with the introduced species because the cultivars evaluated are all introduced.

Table 2.4.7 Experimental yield of selected traditional vegetables at several highlands and lowlands locations (t/ha)

Crop	Aiyura[a]	Aiyura[b]	Kuk[c]	Bubia[d]	Port Moresby[e]	Various locations[f]
Aibika	2.8	–	–	13.2–63.7	4.7–5.7	3.7–4.7
Ginger	–	–	–	–	–	10–23
Highland *pitpit*	3.1	–	8–18	–	–	3.9–5.0
Rungia	6.4	0–5.0	4	–	–	–
Winged bean						
– pods	3.1	–	–	–	–	–
– seed	–	–	1.6–2.2	–	–	1.1–1.3
– tubers	2.3	0–2.9	–	–	–	1.5–1.9

[a] The data are an average of two trials that evaluated 25 species of traditional and introduced vegetables for their suitability for schools (Akus and Nema 1995).

[b] The data for rungia and winged bean are two time-of-planting trials. Figures given here are yields for the worst and best months to plant (R.M. Bourke unpublished data).

[c] The data are from experiments on three vegetable species at Kuk near Mount Hagen (Powell 1982). Highland *pitpit* yields are total stem yield (edible and inedible portions). About 30% of *pitpit* stem is edible when cooked in an earth oven.

[d] The *aibika* data from Bubia are the range of yields from an evaluation of 41 varieties (Sutherland 1984/85). Mean yield was 36.4 t/ha. The author cautions that plots were not replicated and edge effects may have resulted in a higher apparent yield when plot yields were converted to t/ha.

[e] The *aibika* figure from Port Moresby is the mean yield for a trial that evaluated 12 varieties and for a method of propagation trial (Westwood and Kesavan 1982). The authors also present data on the nutritional value of eight vegetable species.

[f] *Aibika* yields are the averages of the best treatments from a time of weeding trial and a chicken manure fertiliser trial conducted at Laloki near Port Moresby. Each figure is the average for three varieties and two trials (Sowei and Osilis 1995; Sowei et al. 1996). Ginger data are from a coconut interplanting trial at Keravat (Gallasch 1976). The highland *pitpit* data are from a trial with two varieties at Tari in Southern Highlands Province (Rose 1980). Yields are for edible portion. The winged bean seed and tuber yield data are from an evaluation of 10 varieties at three lowlands (Laloki, Lae, Waigani) and three highlands (Aiyura, Kuk, Wapenamanda) sites over two years (Kesavan and Stephenson 1982).

Table 2.4.8 Experimental yield of 12 traditional and 13 introduced vegetable species at Aiyura, Eastern Highlands Province[a]

Crop	Part eaten	Yield over total harvest period (t/ha)	Period to first harvest (weeks)	Period to last harvest (weeks)
Traditional vegetables				
Aibika	Leaves	2.8	24	76
Amaranthus	Leaves	1.5	14	54
Bean, winged	Pods, seed	3.1	20	29
Bean, winged	Tubers	2.3	45	45
Bottle gourd	Young fruit	8.6	19	27
Cyanotis moluccana	Leaves	10.1	14	76
Dicliptera	Leaves	5.0	15	76
Karakap	Leaves	2.8	14	70
Rorippa	Leaves	0.9	12	21
Oenanthe	Leaves	9.7	14	76
Pitpit, highland	Young stem	3.1	17	69
Pitpit, lowland	Inflorescence	0.5	49	82
Rungia	Leaves	6.4	15	76
Introduced vegetables				
Bean, climbing	Pods, seed	3.3	15	25
Bean, dwarf	Pods, seed	2.5	14	22
Bean, lima	Pods, seed	3.1	23	72
Cabbage	Head (leaves)	10.5	20	63
Ceylon spinach	Leaves	6.0	15	68
Choko	Leaves	5.9	15	74
Choko	Fruit	34.5	18	74
Cowpea	Pods, seed	3.5	19	56
Pak choi	Leaves	3.4	20	25
Pea	Pods, seed	0.7	12	14
Pumpkin	Leaves	8.4	16	74
Pumpkin	Fruit	59.8	19	71
Russian comfrey	Leaves	11.6	15	77
Silverbeet	Leaves	16.4	16	63
Spinach	Leaves	0.3	27	34

[a] Figures given here are the average from two trials conducted at Aiyura between 1979 and 1982. The authors also present data for dry weight yield.

Source: Akus and Nema (1995).

Temperate-climate vegetables were produced commercially from 1965 until the late 1990s at Kabiufa High School, west of Goroka. This operation depended on high levels of chemical input and is reported to have closed because of build-up of chemical residues in the soil. In a paper describing the enterprise, average yields for sweet potato and six introduced vegetables were given (Table 2.4.9).

Much of the available information on onion research in PNG is summarised in a paper by Wiles (2001a). The yield range for experiments on onion is crop failure (0 t/ha) to 45 t/ha. The most common range at Laloki was 10–40 t/ha and the most common range at Aiyura and other sites in Eastern Highlands Province was 8–20 t/ha.

An indication of the range of yields for introduced vegetables that have been measured in experiments is presented in Table 2.4.10 for the highlands and Table 2.4.11 for the lowlands.

Fruit

No published yield data are available for fruit trees grown under village conditions in the lowlands or highlands, but some yield data have been recorded at research stations and other locations. Data for 10 species of introduced fruit trees at the Lowlands Agricultural Experiment Station at Keravat are given in Table 2.4.12. The number of trees and duration of recording varies between sources and over time.

A detailed analysis of yield data for durian, mangosteen and rambutan is summarised in Table 2.4.13. Considerable variation in yield occurred between years for the three tree species. Most trees failed to fruit in some years.

Mean fruit weight from 18 avocado trees in one trial at Keravat in the late 1970s was 475 g. Some yield data have been published for pineapple from Keravat and for watermelon in the Port Moresby area (Table 2.4.14).

Yield records from 7 'banana' mango trees at the Pacific Adventist College near Port Moresby in 1994 indicated that trees yielded up to 300 fruit each, or about 75 kg/tree. Planting material of the mango varieties Banana Callo, Kensington Pride and Totapuri ('Rabaul') was made available by NARI at Laloki. NARI reports average fruit yields of 300 fruit per tree for Banana Callo and more than 400 fruit per tree for Kensington Pride and Totapuri. A mean fruit size of 270 g, 470 g and 580 g at Laloki for these varieties and a planting density of 100 trees/ha indicates a potential fruit yield of 8, 19 and 23 t/ha respectively for the three varieties.

Table 2.4.9 Average commercial yield for sweet potato and six introduced vegetable species at Kabiufa High School near Goroka[a]

Crop	Yield range (t/ha)
Sweet potato	20–35
Cabbage	15–25
Carrot	2–5
Cauliflower	2–5
Lettuce	4–13
Radish, red	1–3
Tomato	2–10

[a] Temperate-climate vegetables were produced at Kabiufa High School near Goroka in Eastern Highlands Province from 1965 until the late 1990s. The authors caution that even with a well-managed operation, crop failure can occur and 'yields range from zero upwards'. These data were presented as average yields for their commercial operation.

Source: Dever and Voigt (1976).

Data collected in the late 1970s at Aiyura for experimental yield of pineapple, strawberry, and four types of citrus are presented in Table 2.4.15. Other limited experimental data are available from Aiyura, for example, fruit production of naranjilla was recorded as 7.5 kg/tree (130 fruit/tree; 58 g/fruit) in the first six months of bearing in an observation plot.

Nuts

Yield data from both village gardens and research stations for edible nut species are limited. More village and experimental data for edible nuts have been recorded from Solomon Islands than from PNG.

The most important edible nut in the highlands is pandanus nut (*karuka*). Recordings were made of planted village *karuka* nut in two locations in the Tari basin in Southern Highlands Province from 1976 to 1980. The number of syncarps (fruit that contain the nuts) varied greatly between years, with a range of 0.2–1.5 syncarps per bearing tree. The edible nut was 8% by weight of a pandanus syncarp. Observations of the pattern of *karuka* bearing at six locations from Oksapmin in the west to Kainantu in the east over a 7–10 year period indicated that the size and timing of the harvest varies considerably from year to year and between locations.

Galip (*Canarium* spp.) nut yields under PNG village conditions are not known. However, detailed observations have been made in village and experimental

Table 2.4.10 Experimental yield of 12 introduced vegetable species at various highlands sites (t/ha)

Crop	Three sites in SHP[a]	Various sites, three provinces[b]	Recommended varieties[c]	Average period to the first harvest (days)[d]
Bean, common	7–8	7–24	7–24	95–100
Broccoli	3–9	1–20	9–14	74–84
Brussels sprout	2–14	–	–	–
Cabbage	11	–	–	–
Cabbage, Chinese[e]	11–45	–	39	56–70
Carrot	3–15	0–45	8–40	142–145
Cauliflower	0–15	1–4	–	70–86
Lettuce	–	1–21	13–21	102
Marrow	–	9–25	21	–
Onion	–	20–51	9–16	122–137
Tomato	8–16	9–28	13–15	120–125
Zucchini	–	17–25	19–25	125

[a] Data from Southern Highlands Province were recorded at Piwa (near Tari), Kuma and Wambip (near Mendi). Figures are lowest and highest marketable yield of different varieties in variety evaluation trials, averaged over the three sites (Kanua and D'Souza 1985).

[b] Data were recorded at Yani (near Gumine, Simbu Province), Aiyura (Eastern Highlands Province) and Kuk (near Mount Hagen, Western Highlands Province). Figures are lowest and highest marketable yield of different varieties or fertiliser treatment in variety evaluation and fertiliser trials, averaged over the three sites (Kanua 1990).

[c] Yields for the recommended varieties are based on the trial data from Southern Highlands Province, Yani and Aiyura (previous two columns). Yield ranges are from a more limited number of varieties than the other datasets. Thus they give a clearer picture of the yield range of the best varieties under experimental conditions, as distinct from data on all varieties evaluated (Kanua et al. 1993).

[d] Average period to the first harvest is the range of periods from these six sites.

[e] The term Chinese cabbage here covers a number of types, including those in the Chinese cabbage cultivar group and those in the pak choi cultivar group.

plots in Solomon Islands on three species of *galip* nut. Average tree yields for *C. indicum* were 100 kg of nut-in-shell (NIS)/tree/year (range 50–300 kg) and mean kernel yield was 16 kg kernel/tree/year. The average kernel proportion was 17% of the weight of nut-in-shell. *Galip* is rarely grown as a monoculture but, at a planting density of 100 trees/ha, yields an equivalent of 10 tonnes NIS/ha/year. Tree and kernel yields were lower for *C. harveyi* (50 kg NIS/tree/year and 12 kg kernel/tree/year) and for *C. salomonense* (25 kg NIS/tree/year and 5 kg kernel/tree/year).

Okari (*Terminalia kaernbachii*) yields have been recorded in a village in Western Province, in Oro Province and from experimental plantings at Keravat. They indicate that production of *okari* nut varies a lot from tree to tree and also from year to year. Experimental plantings at Keravat gave a yield of 16–82 kg fruit/tree/year in the late 1970s. Recordings from the same trees over a three-year period in the early 1990s gave a yield of 2.6 tonnes fruit/ha/year. On the Managalas Plateau in Oro Province yields were recorded as 480 nuts per tree,

Table 2.4.11 Experimental yield of 10 introduced vegetable species at various lowlands sites (t/ha)

Crop	Laloki dry season[a]	Mount Diamond dry season[b]	Waigani–Tanubada[c]	Various locations
Bean, climbing	0.4–4.0	–	–	–
Bean, dwarf	0.1–1.0	–	–	–
Cabbage	14–41	32–63	5–10	15–63[d]
Cabbage, Chinese[e]	4–13	28–40	10–22	–
Capsicum	9–19	–	15–27	3–7[f]
Cauliflower	9	–	–	–
Cucumber	4–25	–	0.4–6.0	–
Eggplant	20–75	–	–	–
Lettuce	–	–	3–9	–
Silverbeet	25–33	–	–	–
Tomato	35–45	–	9–18	30–60[g]
Yam bean	–	–	–	13[h]

[a] Figures are lowest and highest yield of different varieties in evaluation trials conducted at Laloki near Port Moresby. These data are for total (not marketable) yields (Blackburn 1976).

[b] The Mount Diamond data are commercial yields from a high school near Port Moresby (Blackburn 1976).

[c] Data from Waigani and Tanubada near Port Moresby are the lowest and highest yield of different varieties in evaluation trials (Kesavan 1977).

[d] Cabbage yield data under 'various locations' are the range of yields for the best varieties from variety and fertiliser trials conducted at seven sites on the Gazelle Peninsula of East New Britain Province (Wiles and Mwayawa 2001).

[e] The term Chinese cabbage here covers a number of types, including those in the Chinese cabbage cultivar group and those in the pak choi cultivar group.

[f] Capsicum yield under 'various locations' is from an experiment conducted near Goroka which evaluated the effect of sheep manure and inorganic fertiliser. Yield figures are the ranges for different treatments (Nukundj et al. 1997).

[g] Tomato yield under 'various locations' is the most common range from many trials evaluating a large number of tomato varieties and breeding lines at Laloki near Port Moresby. The range of yields recorded was 3–135 t/ha (Bull et al. 1985).

[h] The yam bean yield is the mean from an experiment at Keravat, where the best spacing treatment yielded 20 t/ha (Bourke 1982).

with an estimated average yield of 5 kg/kernel/tree. Observations in Solomon Islands indicate that the kernel is 5–10% of the fruit weight.

No yield data are available for sea almond or *pao* nut (*Barringtonia procera*) in PNG. In Solomon Islands, estimated yields of sea almond are 10–50 kg fruit/ha/year, with the kernel 6–12% of the fruit weight. Estimated yields of *B. procera* in Solomon Islands are 10–50 kg fruit/tree/year, with the kernel 9% of the fruit weight, giving an estimated yield of 1–5 kg kernel/tree/year.

Table 2.4.12 Experimental yield of 10 fruit species at Keravat, East New Britain Province

Crop	1970s recordings[a] (kg/tree/year)	1980s recordings[b] (kg/tree/year)	1990–1992 recordings[c] (t/ha/year)
Carambola	–	50	6.1
Durian	50–60	104	5.7
Egg tree	–	–	7.3
Langsat	100–140	39	–
Lime	460–700	–	–
Malay apple, giant	100–130	–	–
Mangosteen	6–9	15	2.5
Pulasan	–	20	1.7
Rambutan	–	29	2.1
Santol	–	15	0.8

[a] The data source is Aburu (1982:117–120), who also gives ranges for the number of fruit per tree per year for 34 fruit and nut species. The duration of data is not stated, but is probably for 1978 and 1979 (and sometimes for 1980). Data for West Indian lime are from a formal trial that ran for about 12 years.

[b] The data source is Woodhouse (1991). Some observations are from the same trees as the 1970s data. He also gives average fruit weight for these seven species. Duration of recording is 10 years for mangosteen, 9 years for durian and one year for the other species. Therefore the figures for durian and mangosteen are more reliable than for the other species.

[c] Source for the 1990–1992 data are recordings by S. Woodhouse (in Bourke et al. 2004:185–186). The data are mostly from the same trees as the 1980s data, and are expressed as t/ha/year. They have been aggregated from monthly records.

Table 2.4.13 Experimental yield and yield potential of three fruit species at Keravat, East New Britain Province[a]

Crop	Sample size and span of data collection	Mean yield per tree (kg/tree/year)	Yield of best trees (kg/tree/year)	Assumed planting density (trees/ha)	Potential yield (t/ha/year)
Durian	14 trees; 1980–1992	67	150	50	7.5
Mangosteen	11 trees; 1982–1992	14	20	280	5.6
Rambutan	24 trees; 1989–1992	12	25	100	2.5

[a] These data are from some of the same trees as those in Table 2.4.12, although the actual trees and period of data collection differs between the datasets. The potential yield is derived by multiplying the yield for the best trees by the assumed planting density and dividing by 1000 to convert from kilograms to tonnes.

Source: Wiles (1997).

Table 2.4.14 Experimental yield of pineapple and watermelon at various lowlands locations

Crop	Location	Yield (t/ha)	Source
Pineapple[a]	Keravat	26.5	Bourke (1976a)
Pineapple[b]	Keravat	16.5	Gallasch (1976, 1980)
Watermelon[c]	Laloki	8.6–21.5	Blackburn (1976)
Watermelon[c]	Mount Diamond	57.4–108.9	Blackburn (1976)
Watermelon[c]	Waigani and Tanubada	0.7–5.8	Kesavan (1977)

[a] These data are from a trial that compared different planting material for the rough leaf type of pineapple. Harvesting commenced 11 months after planting. Total fruit yield was 26.5 t/ha over four bearing years or 6625 kg/ha/year. Mean fruit weight was 1.25 kg.

[b] These data, also with the rough leaf type of pineapple, are from a trial where various food crops were planted with coconuts. The yield of 16.5 t/ha was recorded in the first 28 months after planting.

[c] All watermelon yield data are for the lowest and highest yields recorded in variety evaluation trials.

Table 2.4.15 Experimental yield of six fruit species at Aiyura, Eastern Highlands Province

Crop	Yield (t/ha/year)	Notes
Grapefruit	20.8	Data on citrus species are from a rootstock/scion trial. Heavy bearing for all four citrus species commenced in the third year of fruiting.
Lemon	20.2	
Orange	16.6	
Mandarin	9.8	
Pineapple	22.3	Production commenced 14 months after planting. This figure is for the first 12 months of bearing for the smooth leaf Cayenne type.
Strawberry	2.0	Yield with good management

Source: Tarepe and Bourke (1982).

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2.5 Rice production

Rice is the most controversial agricultural crop in PNG. Rice imports have been in the range 120 000–208 000 tonnes per year between 1990 and 2005, mostly from Australia (see Section 2.7). In contrast, domestic rice production has been in the range 60–2200 tonnes over the period 1962 to 2000 (Figure 2.5.1, Table A2.5.1), and has averaged about 400 tonnes per year since 1980. This is around 0.25% of rice consumed per year in PNG in recent years. Claims are made for significant local production from time to time, but these are political statements rather than realistic estimates. Production in 2006 was estimated as 300–800 tonnes.

PNG leaders accuse the former Australian colonial administration of discouraging domestic rice production in PNG in order to protect an important export industry in Australia. Since Independence in 1975, plans for a domestic, import-replacement rice industry have been a feature of every government white paper on agriculture. Yet, since 1977, domestic rice production has never exceeded 1% of the amount of rice imported.

Rice growing in PNG

Rice has been grown in many parts of PNG. Before 1900, rice was grown, mainly by Catholic missionaries, in the Bereina area and on Yule Island in Central Province, at Aitape in Sandaun Province, and probably at other places. In inland Finschhafen in the Sarawaget Mountains of Morobe Province, Lutheran missionaries introduced rice growing in the early 1900s and it is today the only place in PNG where it has become a 'traditional' crop.

After 1918, rice growing in Papua (the Southern Region) was a compulsory village activity under the Native Plantation Ordinance (1918). The Papuan colonial administration sent an officer to India, brought Indian instructors to Papua and established a 'fully equipped rice mill' in an attempt to 'make the Territory self-supporting in rice'. For example, the colonial administration promoted village rice cultivation in the Cape Vogel area of Milne Bay Province in 1923–1926. When this initiative failed, it was concluded that rice growing was too labour intensive and the environmental conditions were unsuitable. Cassava was then promoted and successfully adopted in the Cape Vogel area. In New Guinea, rice growing was promoted at Talasea in West New Britain and in East New Britain. On the Gazelle Peninsula, enough rice was produced for a steam-driven mill to be imported. Rice was grown on Umboi Island in Morobe Province until 1941.

During World War II, Japanese troops grew rice on the Gazelle Peninsula in East New Britain, and on New Ireland, but appear to have concluded that sweet potato was a more productive and reliable crop. For example, in Sandaun and East Sepik provinces (then one province), Japanese troops grew sweet potato and Chinese taro, rather than rice, in an attempt to feed themselves after they were cut off from Japan. In

Papua, the Australian military administration made rice growing compulsory at Bereina and introduced a mechanical harvester.

After the war, in 1947, the New Guinea Nutrition Survey Expedition studied village food production in five locations and concluded that the 'wider cultivation of crops such as peanuts and rice, which can be easily stored and transported, would help eliminate regional and seasonal food shortages'. W. Cottrell-Dormer, who was the agricultural officer on this survey, later became the Director of Agriculture in PNG. He was so convinced that rice could be produced satisfactorily at Bereina that he resigned his post as director to personally supervise the Bereina project. At Bereina, machinery was introduced and tractors were used to cultivate relatively large areas.

In the Sepik provinces, in particular around Maprik and Nuku, villagers began growing rice within the traditional shifting cultivation system in the 1950s as part of an indigenous rural development movement led by Pita Simogun at Dagua. Simogun had visited Australia during the war and observed Australian farmer rice-growing cooperatives in the Riverina.

Similar movements occurred in the Markham Valley and in Oro Province. Some of the villagers involved in these movements brought cargo cult elements into the growing of rice.[1] The colonial agricultural extension service attempted to respond to this movement with the introduction of Rural Progress Societies, hand-powered hullers and subsidised purchases. During this period, village rice production was also promoted by government extension services in Morobe (at Finschhafen), Milne Bay, New Britain, Bougainville, Gulf and Central (at Bereina and Kupiano) provinces.

Rice growing since Independence

Domestic rice production in PNG has fluctuated from year to year but has been less than 1500 tonnes per year since 1975 (Figure 2.5.1). Most production has been unirrigated. Rice has continued to be grown spasmodically at Bereina in Central Province,

1 Cargo cults are movements in which it is believed that economic development and political power can be achieved through supernatural means.

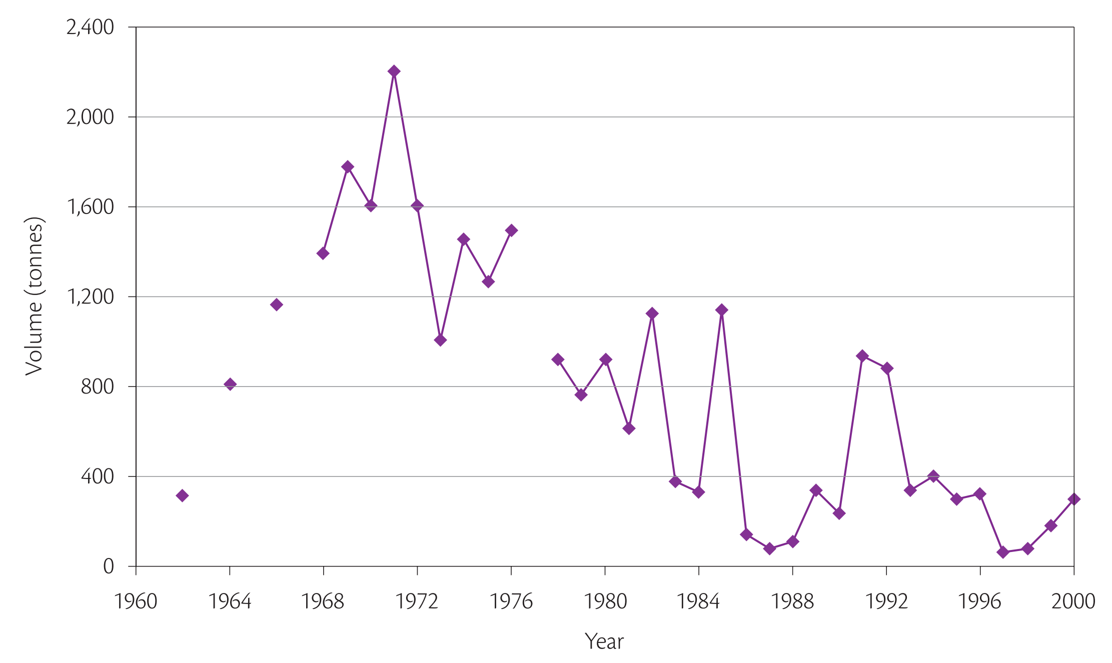

Figure 2.5.1 Estimated rice production, 1962–2000. **Note:** Production figures were not available for 1963, 1965, 1967 and 1977. Sources: 1962–1976: Hale (c. 1978); 1978–1990: DAL (1992:51); 1991–2000: Blakeney and Clough (2001).

as various aid and agricultural investment projects have attempted to make production there sustainable. In the late 1970s the East Sepik Rural Development Project, funded by the Asian Development Bank, made a large commitment to upgrading rice growing and increasing production to 4000 tonnes. However, production in East Sepik Province had almost ceased by 1987.

Small irrigated rice projects have been undertaken near Rabaul using Japanese aid; at Gabmazung near Nadzab in the Markham Valley by the Lutheran Mission; at Bubia with Taiwanese aid; at Cleanwater Creek in the Markham Valley by Trukai Rice; at Erap Research Station, also in the Markham Valley, by DAL; and at Bau near Madang by a Philippines non-government organisation. Rice was grown in Bougainville Province during the civil war (early to mid 1990s), but by 2002 rice growing there had virtually stopped.

From about 2000, production increased in some locations, including in parts of Central, Oro, Morobe, Madang, East Sepik, Eastern Highlands and Simbu provinces. This was in response to the rapid rise in the price of imported rice (Figure 4.3.3). The peak of the recent expansion in rice planting was in about 2001–2003, but production appears to have declined since then. For example, rice production in Madang Province was about 80 tonnes in 2003, 60 tonnes in 2004 and 40 tonnes in 2005. There was little rice being grown in the highlands by 2005. The Trukai Rice depot at Erap in the Markham Valley was able to purchase only 4 tonnes of locally grown rice in 2004 and 7 tonnes in 2005.

Thus locally grown rice remains a minor supplement to the traditional diet in a limited number of locations. At the national level, domestic rice production is still only a small proportion of rice imports and the level of production is a tiny fraction of that of the root crops, sago and banana (see Section 2.2).

Research on rice in PNG

Contrary to assertions that Australia discouraged PNG rice growing, more agronomic field trials have been carried out on rice than on any other crop (Table 2.5.1). Furthermore, many of these trials were done before Independence in 1975. Of the total number of agronomic field trials conducted between 1928 and 1978, 19% were on rice, compared to 11% on sweet potato, the most important food crop for about two-thirds of rural Papua New Guineans. A significant amount of research has also been conducted on rice since 1978.

Table 2.5.1 Agronomic field trials on food crops in PNG, 1928–1978

Crop	Number of trials	Proportion of total trials (%)
Energy and staple crops		
Banana	8	0.6
Cassava	6	0.5
Irish potato	66	5.4
Sugar cane	24	2.0
Sweet potato	136	11.1
Taro	30	2.4
Yam	11	0.9
Other energy crops	5	0.4
Total energy and staple crops	286	23.3
Grain crops		
Buckwheat	1	0.1
Corn (maize)	97	7.9
Rice	234	19.0
Wheat	17	1.4
Total grain crops	349	28.4
Other crops		
Farming systems	30	2.4
Grain legumes	245	20.0
Fruit and nut crops	65	5.3
Vegetables, introduced	237	19.3
Vegetables, traditional	16	1.3
Total other crops	593	48.3
Total trials	**1228**	

Source: Bourke (1982:7–8).

Why rice production has not become sustainable in PNG

A great deal of evidence exists that the colonial administrations of Papua and New Guinea made strenuous efforts to grow rice in PNG in order to offset the costs of imported rice. Given the continued enthusiasm by political leaders and administrators to replace imported rice with domestically produced rice, it is important to understand why rice production has not yet become a sustainable rural industry in PNG.

At least seven detailed investigations on aspects of growing rice in PNG have been undertaken since 1950, a number sponsored by non-Australian-based agencies. A summary of their findings suggests there are three main interrelated reasons why rice has not become a sustainable industry in PNG: these are to do with the environment, with cost efficiencies, and with returns to labour.

Environment

Upland rice has been grown in many parts of PNG, but yields are generally low at around 1000–1500 kg/ha.

Rainfall is too unreliable in some locations in PNG for perennial, unirrigated rice growing. The variation in rainfall from year to year, within the year and in the regularity of the beginning of the wet season is not reliable enough to grow large areas of unirrigated rice (see Section 1.5). This is a major reason why, for example, rice growing has failed to become sustainable at Bereina in Central Province.

Where irrigated rice has been grown, pests, weeds and disease have severely reduced yields. Pests and diseases are not a major problem where fields are shifted every year. Soils in many areas have poor water-holding capacity and are thus unsuitable for irrigated rice.

Economics

The high capital costs of establishing irrigated paddy fields and high production costs per tonne are a severe constraint to the development of a PNG rice industry. The main rice-producing countries of the world have comparatively lower production costs. A number of studies show that the costs of establishing large enough areas of irrigated rice to replace imports would severely distort the PNG economy, would require large subsidies and would result in a substantial increase in the retail cost of rice within PNG. Trukai Industries Limited, the main importer of rice into PNG from Australia, has been growing irrigated rice experimentally in the Markham Valley since 1998, but has been unable to achieve economic yields because of pests, weeds and soil problems.

Until recently, imported rice has been a relatively cheap food. For example, up to 1999 rice gave better value for money than purchased sweet potato, banana or Irish potato in Lae. This position changed with the decline in value of the kina, but taking into account the ease of transporting and cooking rice, it remains a competitive food for urban people in PNG.

Labour

The most important reason that rice cultivation has not become significant in PNG is related to returns on people's labour. Returns to labour are higher in the production of root crops than in rice, both in terms of yield and food energy produced per hour worked (see Section 5.20). Returns from growing coffee or cocoa are also higher than for growing rice in cash income per hour worked. Therefore, after experimenting with growing rice, many villagers decide they are better off growing root crops and export cash crops such as coffee or cocoa. The one place where rice growing has become 'traditional' is in the mountains inland of Finschhafen in Morobe Province, where access is difficult, imported rice is expensive and coffee is costly to market.

Compared with other crops, the cash returns to labour from growing rice for sale are significantly less than for cocoa, oil palm, vanilla, Robusta coffee and sweet potato. Many PNG villagers believe the returns to copra and rubber are too low to make harvesting and selling them worthwhile, so it is not surprising they do not participate in rice growing.

Another reason that rice production has not expanded in PNG is that it does not fit easily with village culture. This is because when a rice crop is ready for harvest, there is a relatively short period when harvest must occur. Unlike the export tree crops or root crops, delays in harvest can result in significant yield loss. Such delays are not uncommon in village communities because of other demands on villagers' time.

Over the last 20 years a number of economists have concluded that PNG is better off to import cheap rice and to export high quality palm oil, coffee and cocoa, than to try to establish a domestic, import-replacement, rice industry. On the basis of these economic analyses, it is unlikely that international aid agencies will provide funds to PNG to establish a rice industry. That does not mean village smallholders should be discouraged from growing rice. But it does mean that import-replacement production levels are unlikely in the foreseeable future.

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2.6 Animal production

The most important domestic animals in PNG are pigs, chickens, cattle, sheep, goats, ducks and rabbits. Horses and swamp buffalo are used as working animals to a small degree. Pigs and chickens were introduced into PNG about 3500 years ago (see History of agriculture). All other species were introduced from the late 1800s by colonial administrations, settlers and missionaries. According to the 2000 census, some 400 000 households or 47% of total rural households are engaged in some kind of livestock production. About 200 000 households own poultry, but systematic efforts to modernise commercial production of meat and eggs have only been made in the last 50 years and only the last 25 years for broiler chickens.

Pigs

The most notable feature of the PNG pig industry is the 1.8 million village pigs, mainly indigenous breeds, that produce some 27 000 tonnes of pig meat annually (Tables 2.6.1, 2.6.3). These pigs are owned by 60% of all households (1990 census). In the highlands provinces, 77% of the population claimed pig ownership. This figure was more than 80% if Eastern Highlands Province was excluded and was as high as 89% in Enga Province.

The average number of pigs per person in various regions of PNG is summarised in Table 2.6.2. It is clear that there are many more pigs per person in the highlands (above 1200 m altitude) than in the lowlands (sea level to 600 m altitude), with more than one pig per person in the highlands. The ratio of pigs to persons is also higher in the intermediate altitude class (600–1200 m) than in the lowlands. The available data suggest that the ratio is higher in inland lowland locations (0.33:1) than in coastal locations (0.25:1), although the difference is not significant. The data on which Table 2.6.2 is based were recorded between the 1930s and 1990s, but about 75% of the observations were made in the 1960s, 1970s and 1980s. There are indications that the number of pigs per person has declined in recent decades, at least in parts of the highlands. It is possible that there has been an overall decline in the number of pigs per person in PNG and the total number of pigs now is less than these figures suggest.

Commercial pigs are slaughtered in four registered abattoirs. Of the 29 600 pigs slaughtered in 2005, the Lae abattoir accounted for 45% and Abunaka, a private pig farm near Lae, 38%. With an average carcase weight of 48 kg, this gives a commercial annual production of 1420 tonnes. However, this does not allow for the very large number of live sales and there has been a steady but slow increase since the 1000–1200 tonne estimates of the 1990s. There are currently about 32 000 pigs on commercial farms and total production is estimated as 2300 tonnes. Sow numbers on large farms may be declining but village production is steadily increasing.

Table 2.6.1 Pig industry characteristics

Type of holding	Herd size	Number of herds	Estimated number of pigs	Trends	Breeds
Smallholder, traditional	1–20	360,000	1,800,000	Static; may be increasing with human population	Native
Smallholder, penned	1–3	2,000	4,000	Growing rapidly	Native
Smallholder, commercial	10–100	100 (including at prisons and high schools)	6,000	Growing steadily	Modern commercial
Middle-sized commercial	100–500	4 (3 institutional)	2,000	Static	Modern commercial
Large-scale commercial	>500	7	20,000 (2500 sows)	Declining slowly	Modern commercial

Source: Updated from Quartermain and Kohun (2002).

Table 2.6.2 Average number of pigs per person in three altitude classes

Altitude class	Ratio of pigs to people	Number of observations
Lowlands (sea level to 600 m)	0.3:1	37
Intermediate (600–1200 m)	0.5:1	33
Highlands (1200–2800 m)	1.2:1	94

Source: Generated from data presented in Table 5.8 of Hide (2003:39–47). Differences are statistically significant.

Poultry

There are some 1.5 million village or household scavenging chickens owned by 27% of households (1990 census). About 50% of households in Milne Bay, Madang and East New Britain provinces kept chickens, but chicken-keeping was not adopted in the highlands until the 1950s. Commercial poultry production only began in the 1970s, fostered by deliberate government policy and protection from imports. Domestic production has grown from around 4000 tonnes in 1980 to 24 000 tonnes in 2005 (Table 2.6.3). Two large companies, one operating through contracted outgrowers, supply the bulk of the frozen chicken market.

A feature of commercial production is the large number of smallholder farmers, perhaps up to 15 000, who purchase day-old hybrid broiler chicks in lots of 50 or 100 from one of the three hatcheries and sell them when grown, mainly as live birds in local markets. Niugini Tablebirds imports fertile eggs of hybrid broiler grandparent stock from which the final chicks are derived through parental crosses, while Zenag Chicken imports fertile eggs of parent stock. The Christian Leaders Training College (CLTC) at Banz in Western Highlands Province buys parent stock from Niugini Tablebirds and produces 30 000–45 000 day-old chicks per week for highland farmers. Total production of day-old broiler chicks from the three hatcheries is about 400 000 per week.

Commercial egg production, dominated by Zenag Chicken, has also grown from essentially nothing in the 1970s to estimated current production levels of 45 million eggs. About 200–300 day-old layer chicks per week are sold to villagers by the Zenag and CLTC hatcheries.

Muscovy duck ownership is increasing, mainly for household meat and egg production in scavenging systems. There are no estimates of total numbers

Table 2.6.3 Estimated livestock numbers and meat production, 2005

Livestock	Component	Number of animals	Offtake[a] (%)	Dressed carcase weight (kg)	Production
Pigs	Village	1.8 million	50	30	27,000 t
	Commercial	32,000		48	2,300 t
Cattle	Large-scale ranch	63,500	15	200	1,900 t
	Smallholder	16,500	15	200	500 t
Sheep	Smallholder	15,000	30	12	54 t
Goats	Smallholder	25,000	30	12	90 t
Chickens	Commercial broilers				17,000 t (frozen)
	Broilers, live sales[b]			1	7,000 t (carcase)
	Commercial layers	161,000			45 million eggs
	Village[c]	1.5 million		0.8	1,850 t (carcase) 6 million eggs
Rabbits	Village	30,000		1.4	168 t

[a] 'Offtake' refers to the number of animals in a herd that are removed for sale or slaughter in a given time period, usually a year. It assumes the herd is not growing, so the offtake is equal to the potential increase over the period (excluding deaths) if all animals are kept. This is then expressed as a percentage of the base herd, not of the total herd.

[b] The live bird broiler production is based on hatchery sales of 149 000 day-old chicks per week, a 1 kg carcase weight and 12% losses.

[c] For village poultry it is assumed that a hen produces 70 eggs per year, of which 30 are available for consumption. Incubation of the other 40 eggs results in 12 surviving chicks to grow into replacement pullets or be consumed. A standing flock has 66 pullets for every 100 hens. Hence a 1.5 million bird flock has 204 000 hens, 135 000 pullets and 1 156 500 young birds being raised to eat. Actual meat bird output from this flock is 2.3 million birds (1.15 million young birds twice a year).

Sources: Industry sources for cattle, commercial poultry and commercial pigs; author estimates for village production.

but there could be more than 10 000 duck-owning families. The National Agricultural Research Institute has a flock of layer ducks and a few farmers are raising domestic pigeons or Japanese quail.

Despite various attempts by the Australian Administration and by the PNG Government to promote layer ducks, domestic pigeons, Japanese quail, geese, turkeys and guinea fowl, there has been no successful development of commercial production.

Cattle

Beef cattle numbers have been static for the last 20 years, averaging around 80 000 head. During the mid to late 1970s a significant effort was made by government to create a village-based cattle industry. This was largely unsuccessful and most 'cattle projects' had failed by the early 1980s. Cattle numbers declined from a peak of 153 000 in 1976 to the current figure by 1991. However, numbers are now increasing again by about 2000 per year. Current industry estimates for numbers on large-scale ranches are 50 000 in the Markham and Ramu valleys, 4000 in West New Britain Province (Numondo Plantation), 2500 in East New Britain Province (Coconut Products Ltd), 6000 in Central Province and 1000 in New Ireland Province. The remaining 16 500 head are in a large number of small herds containing from one to several hundred animals, mainly in Morobe Province but also scattered throughout Western, East New Britain, East Sepik, Sandaun, Madang and the highlands provinces.

Four registered abattoirs slaughter cattle. Around 9700 animals were slaughtered in 2005; 38% in Lae and 45% by Ramu Agri-Industries Ltd. Possibly another 2000 head were slaughtered for local sales. A total of 12 000 head at an average carcase weight of 200 kg gives an annual production of 2400 tonnes (Table 2.6.3). In addition, there have been eight live cattle export shipments to Asia since 2002 totalling around 8000 head. About 1150 live animals were exported in 2005. There is a surplus of higher-priced beef cuts in PNG because the market demand is for cheaper cuts of meat. An economic solution to this problem is to export the better quality meat as part of live animal exports. It is also convenient to collect a large number of cattle from scattered smallholder herds and hold them at a central location (Trukai Industries Limited in the Markham Valley) until ready for shipment.

Only one small dairy farm in PNG produces fresh milk for sale and, while there have been others in the past, there have never been more than six. While milk consumption appears to be growing, local production is not competitive with production in temperate climates. There is little potential for expansion of milk production from dairy cows in PNG.

Sheep and goats

Sheep and goat numbers are small compared to cattle and pigs but are slowly increasing, especially in highland environments (Table 2.6.3). Only 2% of households claimed to own goats in 1990 and less than 1% owned sheep. The highest numbers of sheep owners were in Enga, followed by Simbu, Eastern Highlands and Morobe provinces. The highest numbers of goat owners were in Eastern Highlands and Simbu, followed by Enga Province. Sheep meat is very popular, driven by the availability of inexpensive imported sheep meat that is affordable by many people (see Section 2.9). Large-scale growth of sheep and goat ownership, especially in the highlands, has only occurred over the past 30 years. This is a consequence of deliberate government policy in the case of sheep, but goat numbers have increased without government encouragement. Goat numbers continue to grow and there is potential for household milk production from goats.

Minor species

Domestic rabbits were only introduced into PNG in 1993. It is estimated there are currently 2000 owners with a total of 30 000 animals. Assuming 6000 breeding does, 20 offspring per doe per year and a carcase weight of 1.4 kg, annual production is around 168 tonnes.

South-East Asian swamp buffalo were originally introduced for draft purposes. However, despite much effort over the years, they have not become popular. There may be 4000 animals in PNG, with 80% estimated to be feral. A few buffalo are used for transport, mainly in East New Britain and Madang provinces, where extension efforts were concentrated. Current efforts at using animals for transport are now focused on cattle.

Horses are used for stock work on cattle ranches and for recreation, but there are no estimates of numbers. Donkeys were once used for transportation, but there are none left today.

Estimating livestock numbers and production

There has never been a complete census of livestock in PNG. The best available estimates of the numbers of animals of the major species and total annual meat production in 2005 are given in Table 2.6.3. The data are industry estimates (cattle, commercial poultry, commercial pigs) or those of the author.

Numbers of village pigs and poultry and smallholder sheep and goats can be estimated using three different sets of information:

- A survey of indigenous agriculture conducted by the Australian Administration in 1961–1962 (see Section 6.5). The numbers of pigs and chickens per 100 persons in the surveyed villages can be extrapolated using rural population data from the 1980, 1990 or 2000 population censuses and assuming 1962 levels of ownership.

- Census questions. During each census, rural householders were asked if they owned pigs, poultry, sheep, goats or cattle. Although there are difficulties in using the census data, for example the problem of multiple ownership of animals, the numbers of animals can be estimated from the numbers of owners, aggregated on a provincial or regional basis, and assumed herd or flock sizes.
- A listing of the ratio of pigs to people observed at various locations in PNG (Table 2.6.2). Again, using census data, it is possible to estimate total pig numbers on a regional basis. Hide (2003) contains a comprehensive summary of all the available observations of pig numbers, distribution and ownership.

While these approaches rely upon population census data, all three methods of calculation for village pig, poultry, sheep and goat populations produce estimates within the same order of magnitude for each livestock species.

Stockfeed

Three Lae-based companies make and sell stockfeed for pigs and poultry. A mill previously serving the Port Moresby market is currently inoperative. The three Lae companies produced 52 200 tonnes of stockfeed in 2005. In addition, one major pig producer (Rumion) in the Markham Valley in Morobe Province makes its own feed from home-grown maize and produced 5800 tonnes in 2005. The Evangelical Brotherhood Church (EBC) produces feed for its own operations and sells a little around Lae.

Apart from Rumion and EBC, production is based on imported grain, mainly sorghum. Sorghum imports averaged 26 000 tonnes per year from 2000 to 2004. Around 10% of feed composition is wheat millrun, a local product derived from imported wheat after milling. Locally produced components of feeds include fish meal from PNG canneries and minor quantities of copra meal and limestone. Imports of fully prepared stockfeed are about 37 000 tonnes or 40% of total usage per year.

Efforts are being made to increase the use of local agricultural and fisheries by-products. Estimated PNG production of potential stockfeed ingredients is 33 000 tonnes of millrun, 21 000 tonnes of copra meal, 31 000 tonnes of oil palm kernel meal and 6000 tonnes of fish meal.

Meat consumption

Imports of meat are dominated by sheep meat and beef from Australia and New Zealand (see Section 2.9). This includes a wide range of products from whole sheep carcases through to cheaper lamb cuts to boned beef for canning. These imports rose from around 25 000 tonnes in 1980 to 60 000 tonnes in 1994, as beef and sheep meat replaced earlier imports of chicken, pork and tinned meat (Figure 2.9.1). Sheep meat imports subsequently declined to around 25 000 tonnes by 2001–2003. Around 90% of imported beef is used by the two commercial canneries to produce corned beef, luncheon meat and meat loaf products.

Total meat production is estimated as 58 000 tonnes. To this can be added 30 000 tonnes in imports, giving total meat consumption in PNG of 88 000 tonnes. Thus average meat consumption is about 15 kg/person/year. However, meat is an extremely variable commodity ranging from whole carcases or bone-in cuts through boned meat of variable fat content, to processed and tinned products. Available statistics are inadequate to enable all this to be expressed on a comparable basis. Regardless of the accuracy and composition of these estimates, consumption is very uneven both geographically and socially, with differences in cash incomes and the importance of meat in feasting and custom. Both rural and urban people will spend income on meat whenever possible. However, most of the traditional or village production of pig, poultry, sheep and goat meat never enters formal markets. For the 2000 census, 175 000 households claimed to sell meat in local markets or on roadsides.

Future prospects

Growth in the production and consumption of commercial pig and poultry products is possible only through increases in cash incomes. Cheaper or more accessible feeding options using a wider range and greater quantities of local feed ingredients will assist this growth. Growth potential is much greater for ruminants (cattle, sheep and goats), with continuing opportunities to increase beef and live cattle exports. The current cattle herd uses around 128 000 ha of grazing land. There is an estimated 445 000 ha of grassland that can be grazed by cattle and capable of supporting 300 000 head. In addition, there are perhaps 100 000 ha of land under tree crops that could be used for sheep and goat production if not by cattle. PNG has an advantage in being free from the major livestock diseases such as foot-and-mouth disease, swine fever and Newcastle disease. However, tuberculosis, brucellosis, fowlpox and anthrax are still present or threats and livestock production systems require improved management of parasitic diseases.

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2.7 Rice and wheat imports

Total imports

Rice and wheat have the largest share of any foods imported into PNG. These two cereals attract attention because of concerns that the population is becoming dependent on imported food and because of the largely unsuccessful efforts to produce these crops within PNG (see Section 2.5). The time series on import quantities presented here may help to give the debates about these foods a more factual basis.

Figure 2.7.1 and Table A2.7.1 show the annual quantities of rice and wheat imports from 1961 to 2005. Since 1990, rice imports have averaged 152 000 tonnes per year. This figure includes the exceptionally high import of 208 000 tonnes in 1997 when rice replaced food unable to be produced because of the drought and frosts of that year. But total rice imports fell after 1998, and averaged 151 000 tonnes per year between 1999 and 2005.[1]

Wheat imports have averaged 117 000 tonnes per year since 1990. The average quantity of wheat imported has been approximately 80% of the quantity of rice since 1990. However, these ratios change if the comparisons are made in terms of monetary value or food energy supplied.

Rice imports have increased fivefold since the 1960s, when they averaged about 30 000 tonnes per year. The rate of increase in wheat imports has been greater, with a nearly eightfold increase from an average of 15 000 tonnes in the 1960s. Thus, while wheat imports were about half the quantity of rice imports in the 1960s, they were about the same as rice imports for the first time in 2005.[2] This substitution away from rice and towards wheat is a common feature in many countries.

Initially there were no milling facilities in PNG, so bulk flour was imported. Flour imports began to be phased out from 1977 and by the early 1980s the imports were entirely of wheat, which was milled into flour in PNG. An adjustment is made in the figures presented, by using wheat-equivalent quantities in the years when flour was imported. Australia is the source for almost all wheat imported into PNG.

Trukai Industries Limited has historically dominated PNG's rice imports. A number of smaller companies entered the market after 1998 and by 2005 four were importing rice into PNG, but they were responsible

1 Rice imports increased to about 184 000 tonnes in 2006, with increased sales in the highlands and in Port Moresby. This presumably reflects higher incomes for coffee producers and an improved national economy.

2 Wheat import figures cannot be compared directly with those for rice imports as virtually all rice imported into PNG is consumed by people. In contrast, wheat is converted into flour and in the process about 30% becomes unavailable for human consumption and is used for livestock feed. As well, some wheat (approximately 5%) is milled for livestock feed rather than to make flour; and some flour-based products, such as biscuits, are exported from PNG to other Pacific island countries.

for only about 3% of imports. Until 1998, the most common brand marketed by Trukai Industries was 'Trukai'. The devaluation of the kina in 1997 (see Part 4) led to a rapid increase in price from early 1998 (Figure 4.3.3) and caused a marked reduction in sales. Trukai Industries countered this by importing cheaper rice, marketed as 'Roots'. The new brand rapidly became popular and accounted for about 90% of sales within a few years of its introduction. 'Trukai' brand declined to less than 5% of sales by 2004, but had recovered to about 15% by 2005.

Until 2002 almost all of the rice imported into PNG came from Australia. A significant drought in southern Australia between 2002 and 2005 greatly reduced rice production there and subsequently less Australian rice was available for export. Over this period PNG imported rice from various countries including Vietnam, the United States, China, Egypt, India, Thailand and Australia. The preferred source for PNG rice imports is Australia because of the high quality product and predictability of shipping arrangements. But this depends on future water supply and rice production levels in Australia.

Per person imports

The most important reason for the increase in rice and wheat imports is the increase in PNG's population. A different understanding of the significance of rice and wheat imports can be gained if the average quantity imported per person per year is examined.[3]

Rice

Changes in average per person rice imports in PNG over the period 1961–2005, along with the trend growth rates for each decade, are shown in Figure 2.7.2. In the 1960s, rice imports averaged about 13 kg/person/year, while by the 1990s they were approximately 2.5 times higher, at 34 kg/person/year. Most of this increase occurred in the 1980s, when the imports jumped from the 1970s figure of 22 kg/person/year to 34 kg/person/year. The rapid increase in rice consumption (and therefore imports) between the 1960s and the 1980s resulted in forecasts that, by 2000, Papua New Guineans would be consuming an average of 50–60 kg of rice per person per year. But since 2000, the actual consumption level has been 27 kg/person/year; about half of what was forecast.

The slowing in the increase in rice imports since 1980 is also apparent in the estimates of trend growth rates. Between 1961 and 1970 per person imports increased by 6.3% per year; from 1971 to 1980 they increased by 5.2% per year; and from 1981 to 1990 by 1.7% per year. Rice consumption per person was static between 1991 and 2000 and fell at 0.5% per year from 2001 to 2005. In recent years average rice imports have fallen behind population growth. The per person level of imports has fallen from its peak of 43 kg in 1997 – when more imports were needed because of subsistence food shortages – to 27 kg per person in 2005. The last time per person imports were lower than they were in 2005 was nearly 30 years earlier, in 1977.

Rice consumption also fluctuates about its trend because of changes in prices and the exchange rate (see Section 4.1) and because of food shortages such as those in 1997 (see Section 1.6). Modelling of average per person rice imports suggests that rice consumption is becoming less sensitive to changes in average income. This change is consistent with patterns in other countries where rice consumption reaches a saturation point and may decline after that point is reached. If a saturation point has been reached in PNG, it is notable that it has occurred at a lower level of consumption than in other countries. The wider availability of other staple foods in PNG could explain this pattern. But the large difference in rice consumption between urban and rural areas (approximately 30 kg/person/year higher in urban areas; Tables 2.1.1, A2.1.1) suggests that the plateau in per person rice consumption also reflects a stagnation in rural incomes. Consistent with this explanation is the fact that when average prices for export tree crops are higher and rural households receive higher incomes, average rice consumption increases. A significant increase in the price of rice since 1997, caused by the fall in the value of the kina, is another explanation of the fall in rice consumption (Figure 4.3.3).

3 Average imports per person per year are calculated by dividing annual rice and wheat imports by the total population for that year. The population for each year is calculated from that in 1980 (3.01 million), that in 2000 (5.19 million) and the growth rate between 1980 and 2000 (2.76% per year).

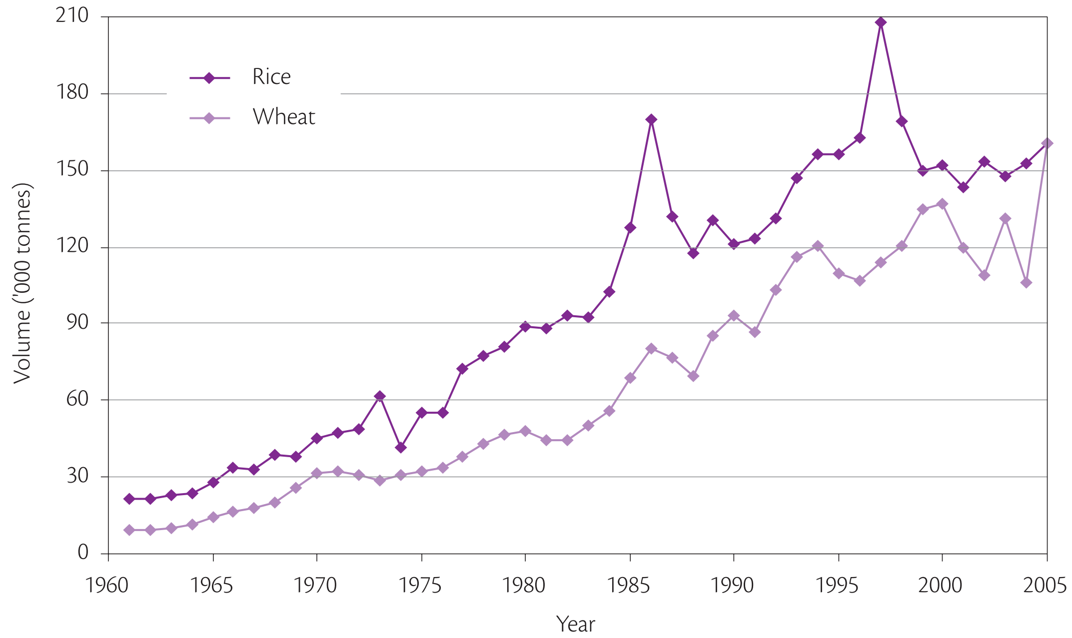

Figure 2.7.1 Volume of rice and wheat imports, 1961–2005. Sources: 1961–1999 Gibson (2001a: Appendix C); 2000–2005 Marketing Department, Trukai Industries Limited, Port Moresby, and Australian Government Wheat Export Authority.

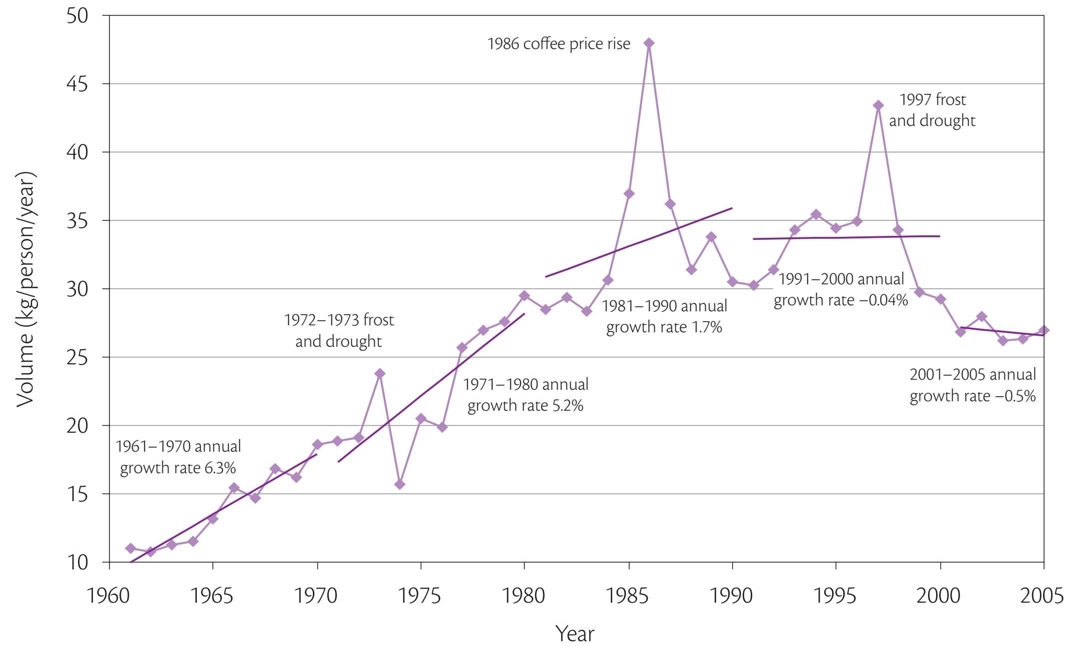

Figure 2.7.2 Average per person rice imports and growth trends by decade, 1961–2005. Sources: 1961–1999 Gibson (2001a: Appendix C); 2000–2005 Marketing Department, Trukai Industries Limited, Port Moresby, and Australian Government Wheat Export Authority.

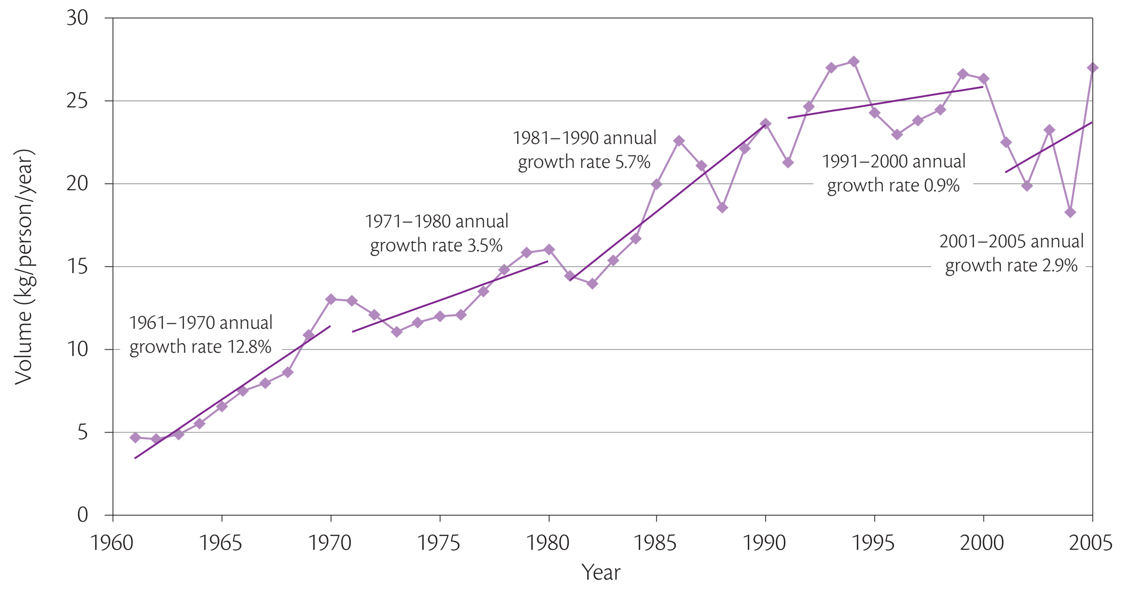

Figure 2.7.3 Average per person wheat imports and growth trends by decade, 1961–2005.
Sources: 1961–1999 Gibson (2001a: Appendix C); 2000–2005 Marketing Department, Trukai Industries Limited, Port Moresby, and Australian Government Wheat Export Authority.

The regional distribution of rice and flour sales also highlights the role of export tree crop prices. In recent years Lae and the Highlands Region have contributed the most to the falling sales of rice and flour, and these are the two sales areas where rural incomes are most affected by the price of coffee. A worldwide decrease in the price of coffee and the increase in the price of imported food in PNG reduced villagers' purchasing power. For example, in mid 1999, the sale of one kilogram of parchment coffee gave a villager sufficient money to buy three kilograms of rice in Goroka. By 2003, a kilogram of coffee could no longer buy a kilogram of rice. Coffee prices recovered to some extent by 2005 but, even so, sale of a kilogram of coffee still only gave enough money to buy about one kilogram of rice. The recovery in coffee prices was associated with an increase in rice sales in the highlands.

Wheat

From 1996 to 2005 wheat imports have been 24 kg/person/year (Figure 2.7.3). Like rice, the per person rate of growth in consumption of wheat products has slowed substantially over the last decade, falling from 5.7% per year in 1981–1990 to 0.9% per year in the period 1991–2000. Since 2001, per person wheat imports have increased at a rate of 2.9% per year. But the instability in previous trend growth rates of wheat consumption, which saw rapid growth in the 1960s and slower growth in the 1970s, means that it is harder to conclude that wheat consumption is also reaching a mature phase, like rice has.

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2.8 Fruit and vegetable imports

PNG imports fruit and vegetables mainly from Australia and New Zealand. The major items imported are Irish potato, onion, apple and, until recently, citrus. In contrast to cereal and meat imports, fruit and vegetables account for only a small proportion of the total value of imported food and are dwarfed by the scale of domestic fruit and vegetable production (see Sections 2.2, 3.1, 3.2 and 3.3). In recent years, PNG's imports of fruit and vegetables have been valued at around K15 million.

Fruit and vegetable imports from Australia and New Zealand averaged about 8000 tonnes per year in the period 1983–2003 (Figure 2.8.1, Table A2.8.1).[1] However, a distinct change in the trend in imports occurred around 1997. From 1983 until 1997 total imports averaged 8800 tonnes per year and did not keep up with population growth. From 1997 to 2003 total imports declined from 9200 tonnes to less than 6000 tonnes; a decrease in annual per person imports of 2 kg/person to 1 kg/person. This fall was prompted by the 1997 devaluation of the kina (see Part 4), which led to imported food becoming more expensive.

While Irish potato comprises more than one-quarter of the total quantity of fruit and vegetable imports, it is less important in terms of value (Figure 2.8.2). The shares of import expenditure on each of the main fruits and vegetables have been roughly constant over the past decade, with the exception of the decline in the value of citrus imports since the mid 1990s and the decline in the value of 'other' fruit and vegetables since the year 2000.

Sources

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Statistics New Zealand website <http://www.stats.govt.nz/default.htm>.

1 Statistics from the exporting countries are used (Table A2.8.1) because these data are more timely and reliable than PNG's import statistics (Table 2.1.2). The population numbers used to calculate the average per person imports in Figure 2.8.1 are the same as those used in Section 2.7 for per person rice and wheat imports.

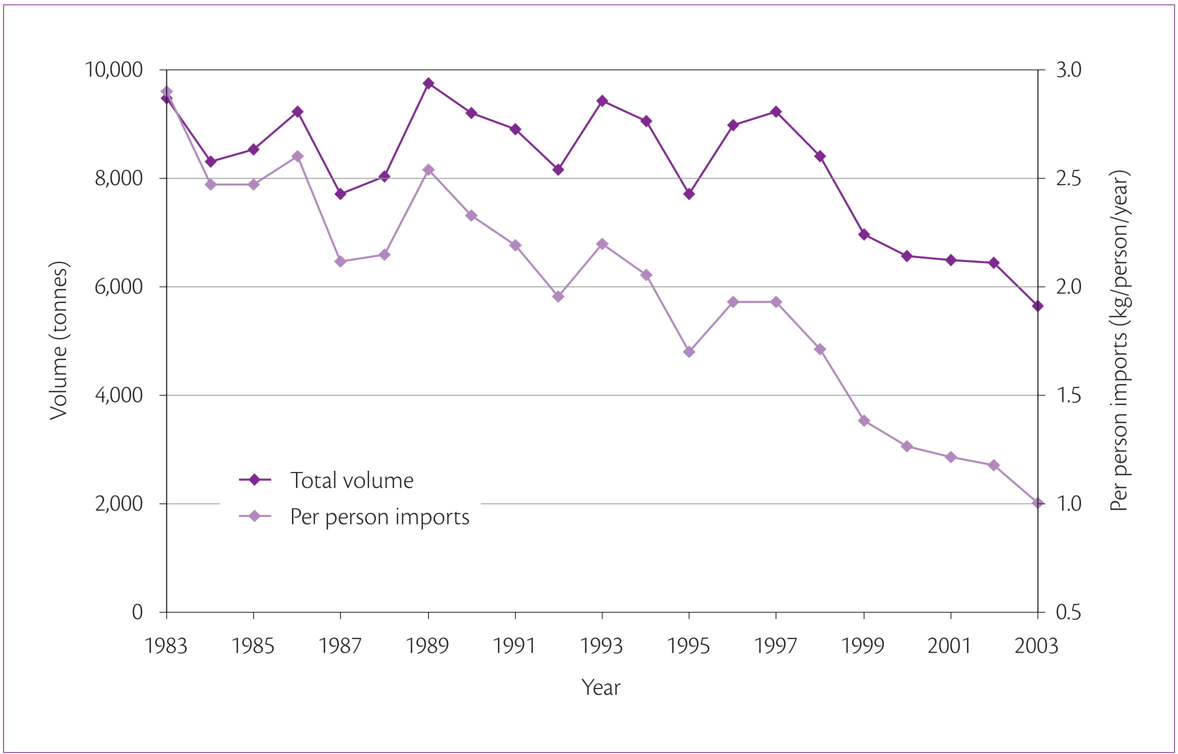

Figure 2.8.1 Volume of fruit and vegetable imports from Australia and New Zealand, 1983–2003.
Sources: Australian Bureau of Statistics; Statistics New Zealand.

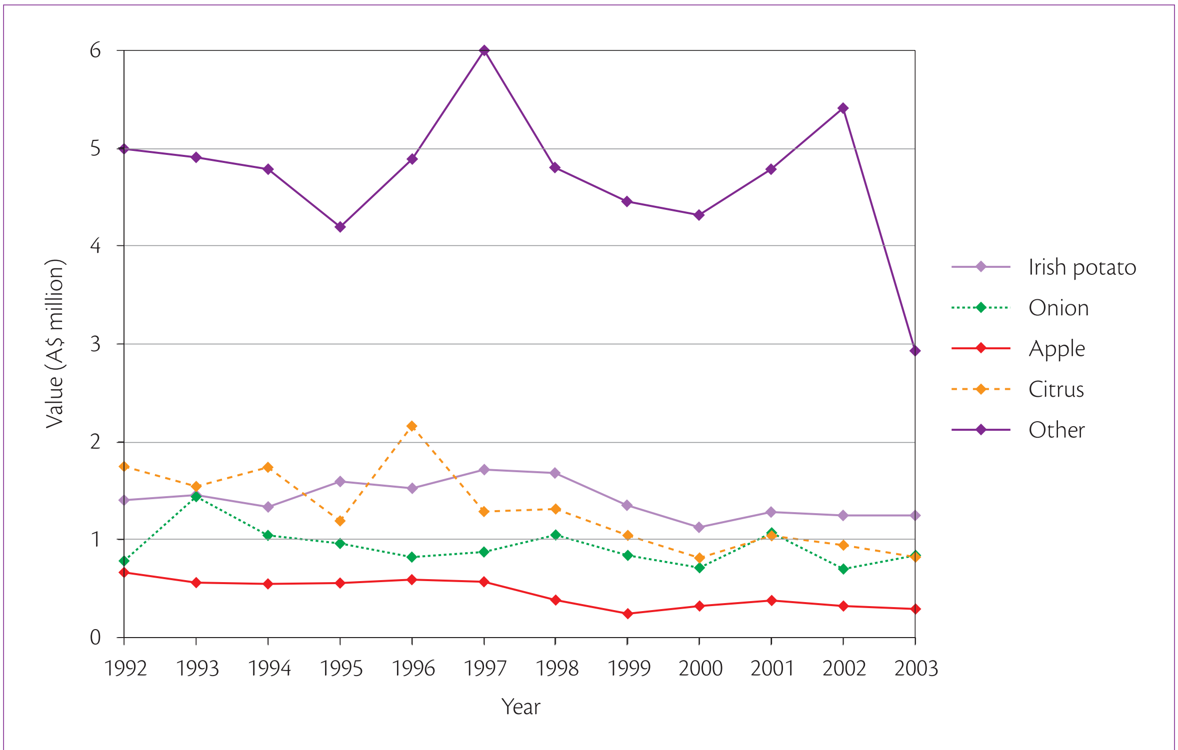

Figure 2.8.2 Composition of fruit and vegetable imports from Australia and New Zealand, 1992–2003.
Sources: Australian Bureau of Statistics; Statistics New Zealand.

2.9 Meat imports

Meat imports into PNG come mainly from Australia and New Zealand, although a limited quantity of tinned pork, chicken, duck and beef is imported from China. The major items imported are sheep meat, beef and offal (lungs, liver, kidneys and other internal organs). Previously, pork, poultry and tinned meat were significant imports but they are now limited by trade barriers (see Section 4.1).

Imported meat together with locally grown meat (see Section 2.6), locally caught fish and imported fish (see Section 2.10) provides scarce protein in people's diets. If the two meat canneries in PNG used only locally grown beef, they would exhaust the entire PNG beef herd in about three months. Meat imports are also important because they are the second most valuable group of food imports, after cereals. In recent years, PNG's meat imports have cost up to K200 million. This has fluctuated with the exchange rate (see Section 4.1), with changing volumes of imports, with changes in the quality of meat imported due to substitution towards cheaper meats, and with consumer substitution of tinned fish for tinned meat. A further reason for interest in meat imports is that claims are sometimes made that meat and meat products (especially lamb flaps) contribute to dietary and health problems.

Meat imports from Australia and New Zealand have averaged about 42 000 tonnes per year since 1983 (Figure 2.9.1).[1] However, from 1983 until 1994 total meat imports rose rapidly, from 25 000 tonnes per year to 60 000 tonnes per year. The amount of meat consumed per person on average almost doubled over this period from 8 kg/person/year in 1983 to 14 kg/person/year in 1994. The annual value of these imports did not rise as fast, however (increasing from about A$40 million in the early 1980s to about A$70 million by the mid 1990s), because over this period the quality of the meat imported was reduced.

The change towards lower quality and cheaper meat is illustrated by sheep meat imports (Figure 2.9.2). In 1983 sheep meat comprised less than one-third of the volume of total meat imports and it was not even the leading individual item imported (tinned meat was). But by 1994 sheep meat had grown to be three-quarters of the total volume of meat imports and it has maintained that share since then.

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1 Statistics from the exporting countries are used (Table A2.9.1) because these data are more timely and reliable than PNG's import statistics (Table 2.1.2). Because Australia and New Zealand account for almost all meat imported into PNG, the trends shown in Figure 2.9.1 are representative of all meat imports. The population numbers used to calculate the average per person imports are the same as those used in Section 2.7 for per person rice and wheat imports.

Figure 2.9.1 Volume of meat imports from Australia and New Zealand, 1983–2004.
Sources: Australian Bureau of Statistics; Statistics New Zealand.

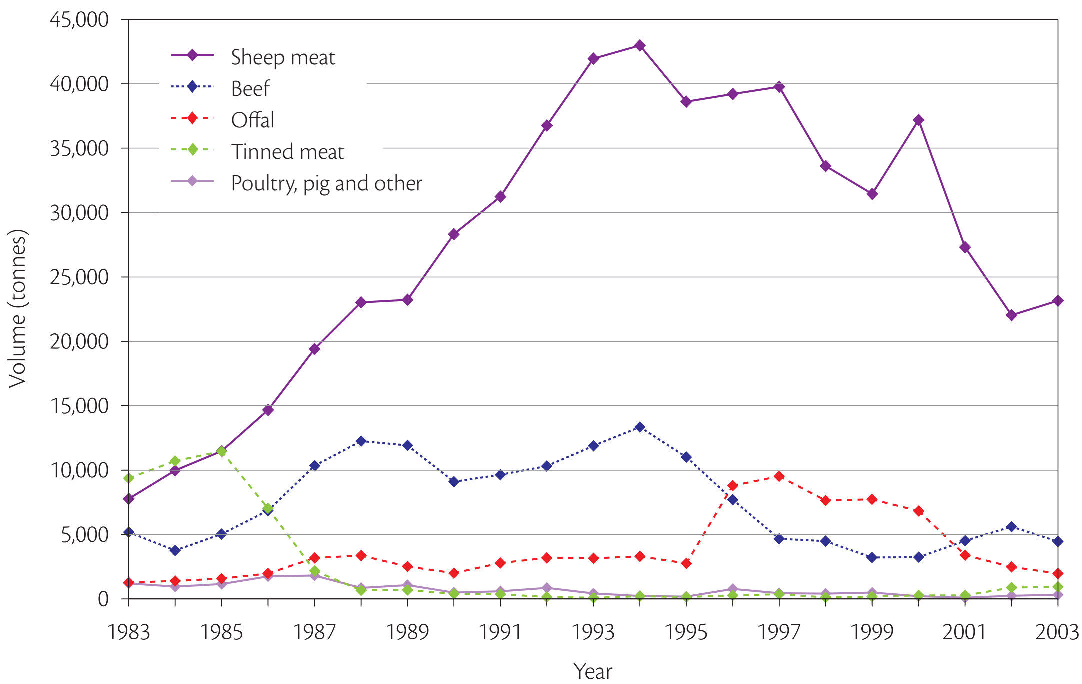

Figure 2.9.2 Composition of meat imports from Australia and New Zealand, 1983–2003.
Sources: Australian Bureau of Statistics; Statistics New Zealand.

Another factor that has caused a reduction in the cost per kilogram of meat imports has been the switch to cheaper cuts of beef and the increased import of offal, which is used as an ingredient in PNG tinned meat. At the same time, imports of the relatively more expensive tinned meat, pork and poultry have been close to zero since the mid 1980s, because of import protection of the domestic livestock industries (Table 4.1.1).

After 1994 the volume of total meat imported fell rapidly (Figure 2.9.1). By 2004, total imports were only 30 000 tonnes, corresponding to less than 6 kg/person/year. This level of meat imports per person is lower than it was 20 years earlier in 1983. The value of these meat imports is also lower, to A$45–A$50 million per year, although the trend in kina terms fluctuates because of the changing value of the kina. The fall in meat import volumes is due to falls in all three of the main imports; sheep meat, beef and offal.

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Statistics New Zealand website <http://www.stats.govt.nz/default.htm>.

2.10 Fish imports

PNG's annual consumption of fish and seafood is between 12 and 25 kilograms per person. Fish makes up around 1% of PNG's dietary energy supply (see Figure 2.1.2), which is much lower than in most Pacific island countries. The amount of fish and seafood consumed in PNG increased from the 1960s until 1980. By 1998–2000 fish consumption had fallen below 1960s levels of around 15 kg/person/year. Consumption was estimated as 12 kg/person/year in 2006 (Table A2.1.1). Other high quality protein sources such as meat, milk, eggs and nuts make up a low proportion of the overall diet (about 20–30 kg/person/year) compared to starchy roots and fruit and other vegetables (around 900 kg/person/year). The low amount of protein in the diet has been a nutritional concern in PNG, causing problems such as inhibited child growth rates (see Section 6.6). It is nutritionally important to increase access to fish (as well as to high quality cereals, legumes and meat).

According to the United Nations Food and Agriculture Organization, demand for fish products in PNG greatly exceeds supply. It has been estimated that people in Port Moresby alone could consume an additional 2000 tons per year of fresh, smoked and frozen fish. However, in PNG, like other Pacific island countries, lack of cash limits the demand for fish. Buying power, even in urban areas, is limited. In the late 1990s, PNG's estimated total fisheries production was 167 000 tonnes (worth US$161 million), while annual national fisheries consumption is estimated to have been around 16 500 tonnes since the late 1980s. The ratio of exports to domestic consumption supports the argument that lack of buying power is a main cause for low fish consumption.

PNG mostly exports higher-value products such as bêche-de-mer (sea cucumber), trochus shell, prawns and tuna, while it imports low-value fish such as tinned mackerel and the barracouta fillets that are often used in fast food outlets (*kai* bars). Locally produced fish and seafood have long been supplemented by imported fish products. In 1996 fish imports for human consumption were 35 500 tonnes. As with overall fish consumption, PNG's fish and seafood imports peaked in the period 1979–1981 then dropped again and have stayed at low levels. Tinned fish, which can be stored without refrigeration for long periods, has been a particularly important supplement to more perishable local fish products. Tinned fish is vital for urban nutrition in PNG, especially among poorer socioeconomic groups.[1]

In real terms fish imports have shrunk significantly. The United Nations commodity trade statistics database (UNComtrade) shows that the total value of fish imports to PNG has declined in dollar figures

[1] People in urban areas tend to consume more fish, rice, biscuits, bread and meat because these products are more accessible (Tables 2.1.1, A2.1.1). The kinds of foods that are more often eaten in rural areas are less accessible in urban areas.

since 1981.[2] In 1981 fish imports totalled US$35 million. By 1998 fish imports were only US$14 million and in 2003 had fallen to US$8 million (Table A2.10.1). This corresponds with the previously noted decline in real per person consumption of imported goods in PNG over the period to the early 1990s. The vast majority of fish imports up to the early 1990s were tinned fish (Figure 2.10.1). Most of this was mackerel from Japan (Figure 2.10.2). The decline in the value of fish imports, however, does not simply mean a decline in consumption of tinned fish, because since the mid 1990s PNG has been canning fish domestically.

In 1995 the International Food Corporation opened a cannery in Lae and started canning mackerel. This is the main reason for the marked shift in the proportions of tinned fish and fresh fish imports between 1990 and 1998 (Figure 2.10.1). By 1998 the value of tinned fish imports had dropped to a fraction of fresh fish imports, with the total value of imports far lower than it had been when imports of tinned mackerel were higher.[3] Because PNG consumers liked the cold water mackerel they had been eating for years, and because it was cheap, the International Food Corporation imported cold water mackerel to use in the Lae factory. Mackerel thus remained by far the largest fish import but, instead of being imported already canned, it was imported frozen (Figure 2.10.3) then canned in Lae. This switch from imports of higher-value tinned mackerel to lower-value frozen mackerel is part of the explanation for the decline in the value of fish imports.

The advent of tuna canning in PNG has contributed to the fall in imports of tinned fish since the late 1990s. From 1995 the PNG Government policy was to tie access to PNG's very large and rich tuna fishing grounds to a commitment to develop onshore processing. In this way several companies that had been fishing for years as foreign fleets in PNG waters were enticed to re-label their fleets as 'locally based' and build canneries and/or loining plants.[4] The first was the Filipino fishing company RD, which established a cannery in Madang in 1997. In 2004 the South Seas Tuna Corporation (SSTC) started a loining plant in Wewak, using fish from a locally based Taiwan-owned fleet. In 2006 another Filipino fishing company, Frabelle, opened a loining plant and cannery in Lae. As well as exporting, RD has been selling tinned tuna domestically. Furthermore, increases in the price of tinned beef have apparently steered consumers towards tinned tuna in recent years (tinned tuna now retails for less than half the price of tinned beef) (see Section 2.9). This has led to the meat canning factory in Port Moresby also canning tuna.

While the trade situation regarding cold water mackerel is straightforward because this fish is only imported, tuna production in PNG is less clear cut in terms of imports versus domestic production. For example, RD and Frabelle are wholly owned PNG subsidiaries of large international companies. While

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2 Data for this section are based on datasets available for PNG fishery imports in the commodity trade statistics database compiled by the United Nations (UNComtrade). For the years 1981–1990, the Standard International Trade Classification (SITC) Revision 1, 3-digit codes (which contain only two commodity descriptions – 'fish, fresh & simply preserved' or 'fish, in airtight containers, not elsewhere specified & fish preparations') are the only data available. For figures since 1998, the Harmonized System (HS) 1992 five- and six-digit codes became available (with more detailed commodity descriptions), and for the years 2002–2003 HS 2002 six-digit codes (the most detailed commodity descriptions) are available. There are discrepancies between the sets of data. For example, the general category of 'fish, fresh & simply preserved' (commodity code 031) from a particular country for a particular year should equal the sum of specific categories of chilled or frozen fish from the same country and same year, but occasionally these numbers are not equal across the different datasets. Where there are discrepancies, figures from the set indicating a larger volume of trade have been used.

3 The United Nations trade statistics on value are at odds with the 2002 FAO fisheries country profile of PNG, which uses weight to assert that tinned fish still made up 95% of PNG's fish imports in the early 2000s.

4 Loins are pieces of fish body meat, with the bones, skin and guts removed. Cooked loins are ready for canning. This part of the canning process cannot be mechanised, so is labour intensive. The high labour costs in Europe, the United States and Japan mean these countries are not competitive in fish canning, so they import cooked loins then complete the mechanised stages of the canning process domestically. This enables countries that are no longer competitive in fish canning to keep canneries open for political reasons, even though most of the labour is actually offshore.

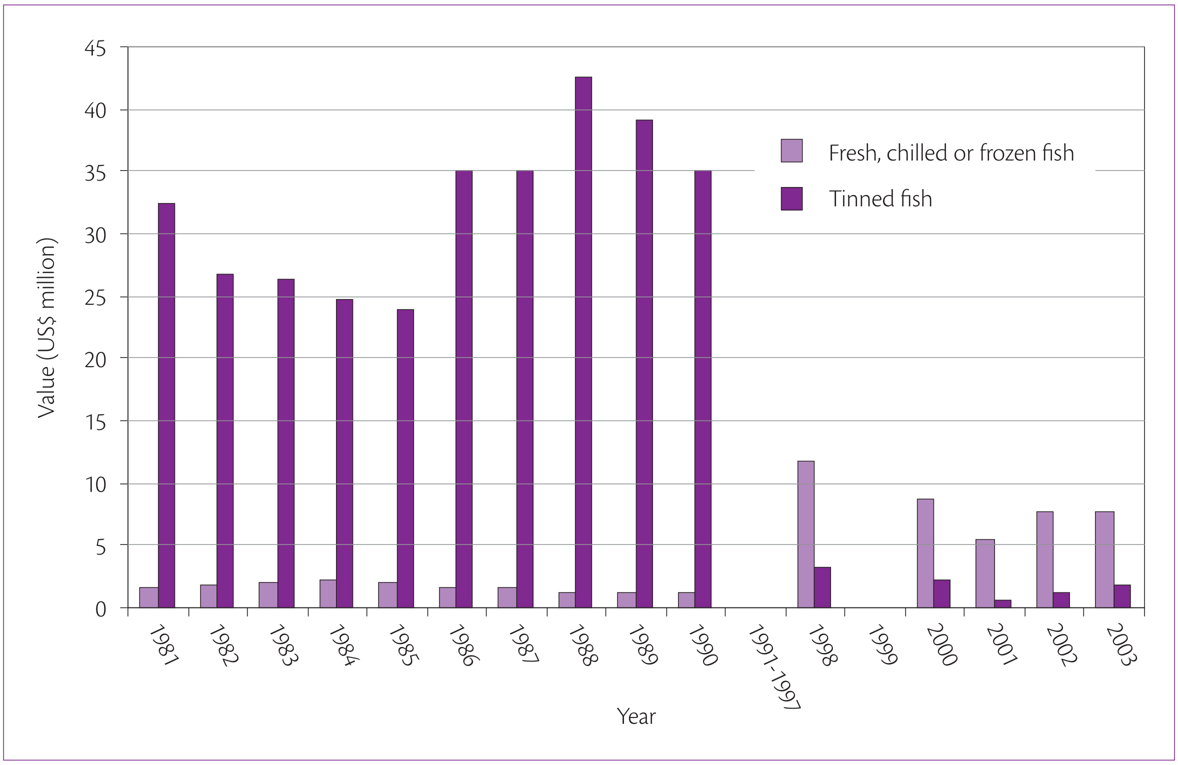

Figure 2.10.1 Value of fresh and tinned fish imports, 1981–2003. **Note:** Data are not available for the years 1991–1997 and 1999. Source: United Nations (2005).

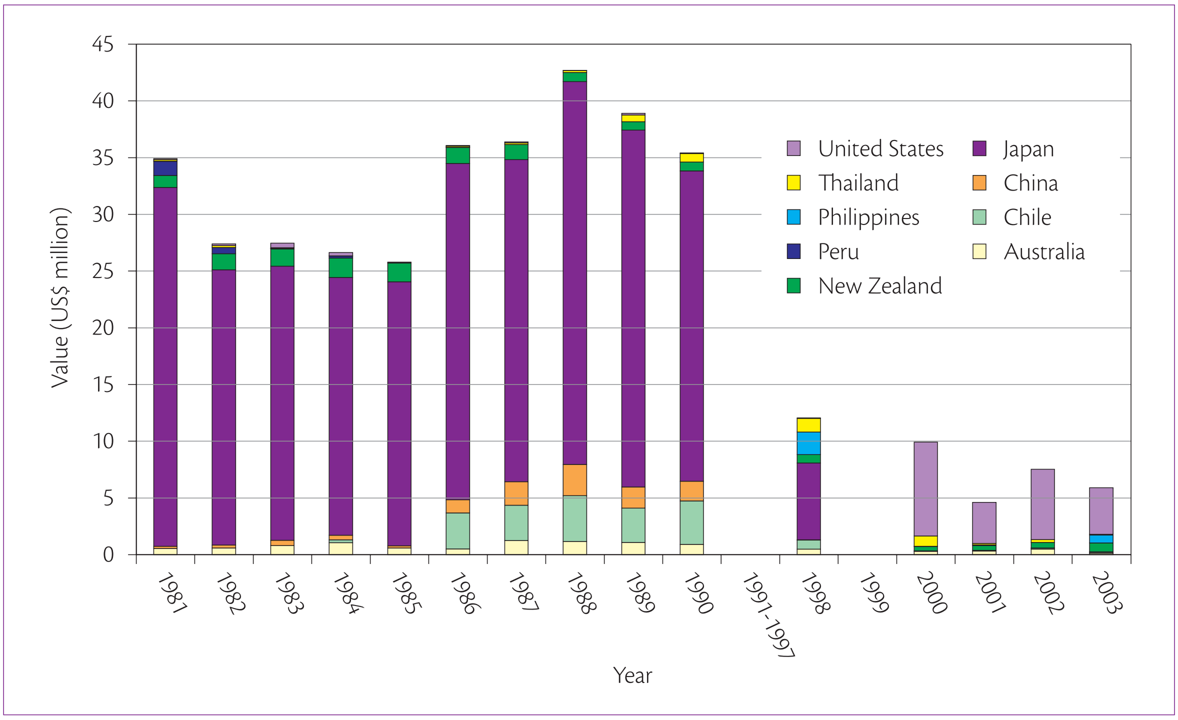

Figure 2.10.2 Value of fishery imports by major source country, 1981–2003. **Note:** A 'major source country' was defined as having import values over US$1 million for one or more years. Data are not available for the years 1991–1997 and 1999. Source: United Nations (2005).

they both have a number of fishing vessels registered as domestic by certain official criteria, these vessels are not really locally owned and operated in a broader sense. RD's vessels are owned by Philippines-based interests who contract them to RD PNG and are crewed mostly by Filipinos recruited through a Philippines-based company. The fleet supplying SSTC is similarly tenuously 'local', as are the purse seine vessels in Frabelle's fleet. (Frabelle is also intending to run a fleet of small 'pump boats', which will have more local input.)[5]

[5] A purse seine vessel carries and operates a net called a seine that hangs vertically in the water with lead weights at the bottom and floats at the top. When the vessel finds a school of fish, it encircles the fish with the seine. A wire threaded through the bottom of the net is then drawn closed, trapping the school.

Pump boats are small, wooden, single-hulled vessels with outriggers, used in some parts of the Philippines. They are powered by diesel engines and 5–8 crew can stay out at sea for several days on them, fishing with handlines.

Furthermore, while PNG's fishing grounds are the richest for tropical tuna in the region, tuna is a migratory species, so the fleets tend not to stay in one national area, but roam across the Pacific following the fish. A regional agreement called the Federated States of Micronesia Arrangement gives reciprocal fishing rights to nine countries of the western and central Pacific, prioritising locally based fleets. Thus a substantial proportion of the catch from the PNG-based vessels associated with the onshore processing factories is caught by foreign crew on foreign-owned vessels, and they may have been fishing outside PNG's fishing zone. Notwithstanding these issues that complicate the nationality of PNG's tinned tuna, trade figures show a low rate of imported frozen tuna (Figure 2.10.3), so the tuna used in the RD cannery and SSTC loining plant has been classified as domestically produced.

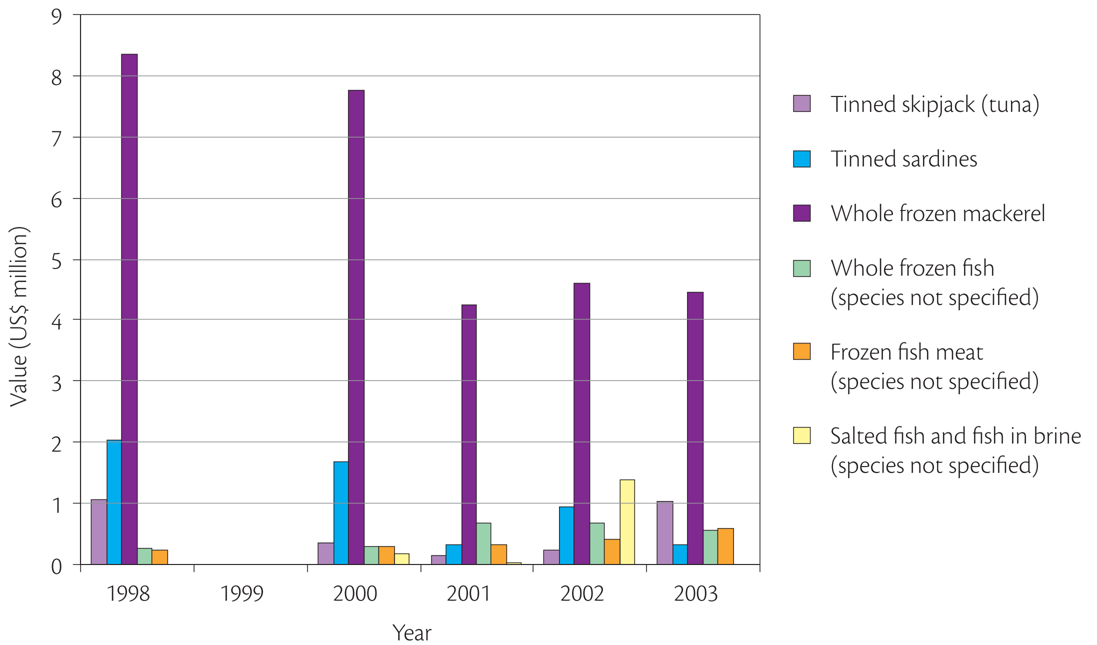

Figure 2.10.3 Value of fishery imports by main commodity, 1998–2003. **Note:** A 'main commodity' was defined as having import values over US$0.5 million for one or more years. The commodity description 'prepared/preserved, not mince' is presumably made up mostly of tinned fish (neither the word 'can' nor 'tin' are used in the commodity descriptions). Data are not available for the year 1999. Source: United Nations (2005).

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