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).

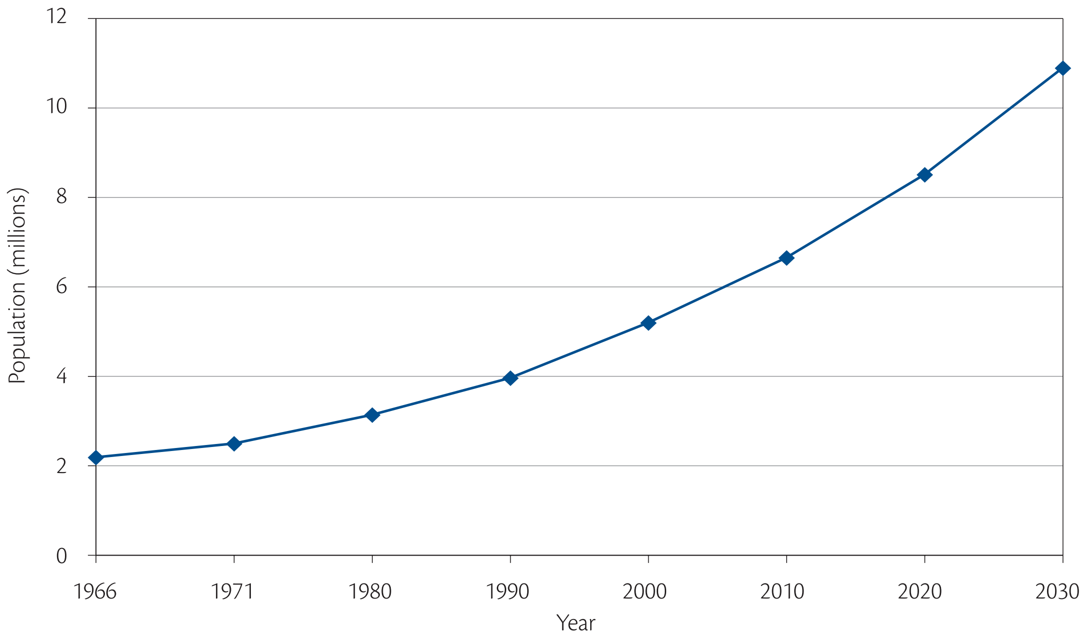


Figure 1.1.1 Population growth 1966–2000 and projected growth 2000–2030 at a constant 2.5% per year.
Sources: 1966–1990: DNPM (1999); 2000: NSO (2002).

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).

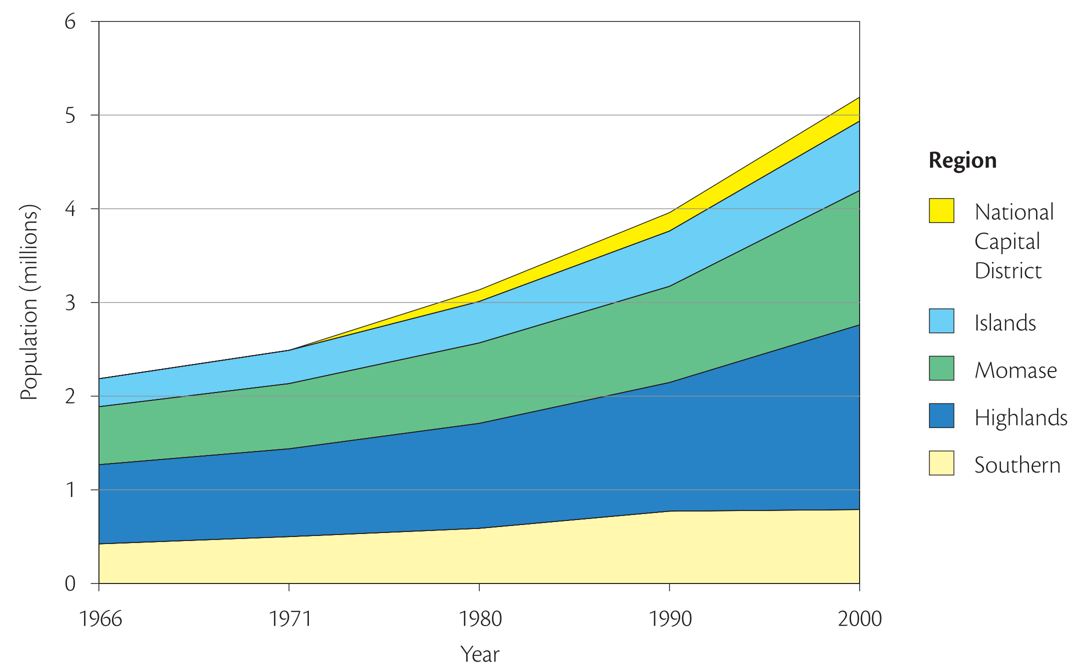


Figure 1.1.2 Population growth by region, 1966–2000. Sources: 1966–1990: DNPM (1999); 2000: NSO (2002).

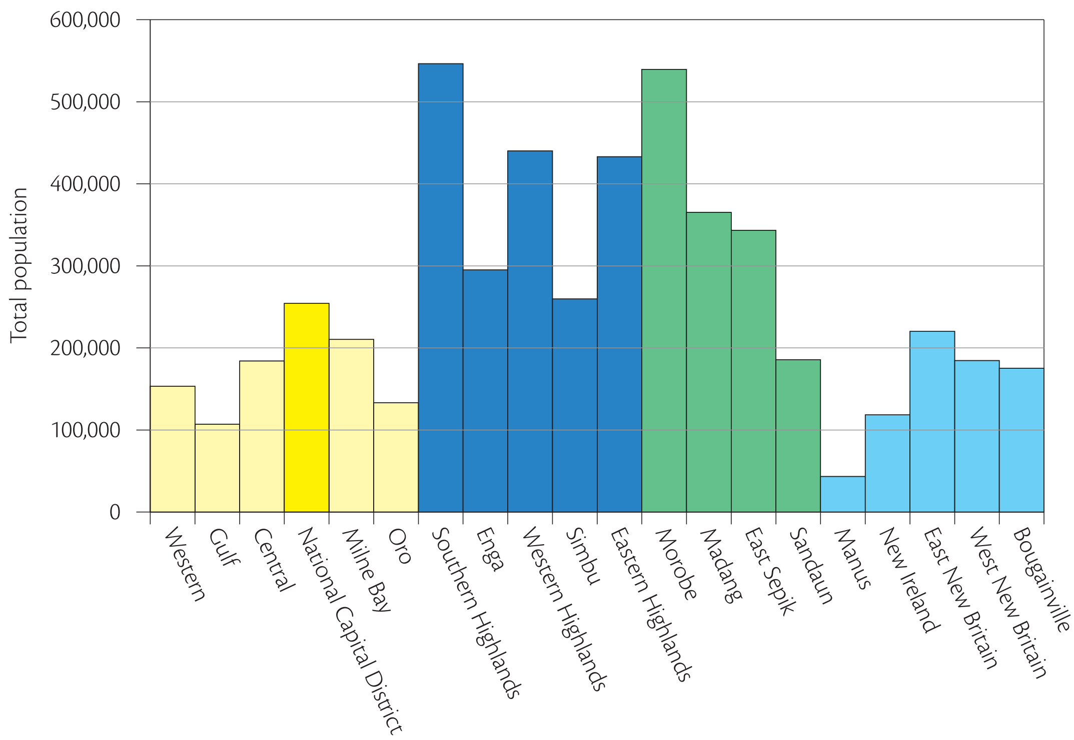


Figure 1.1.3 Total population by province, 2000. Source: NSO (2002).

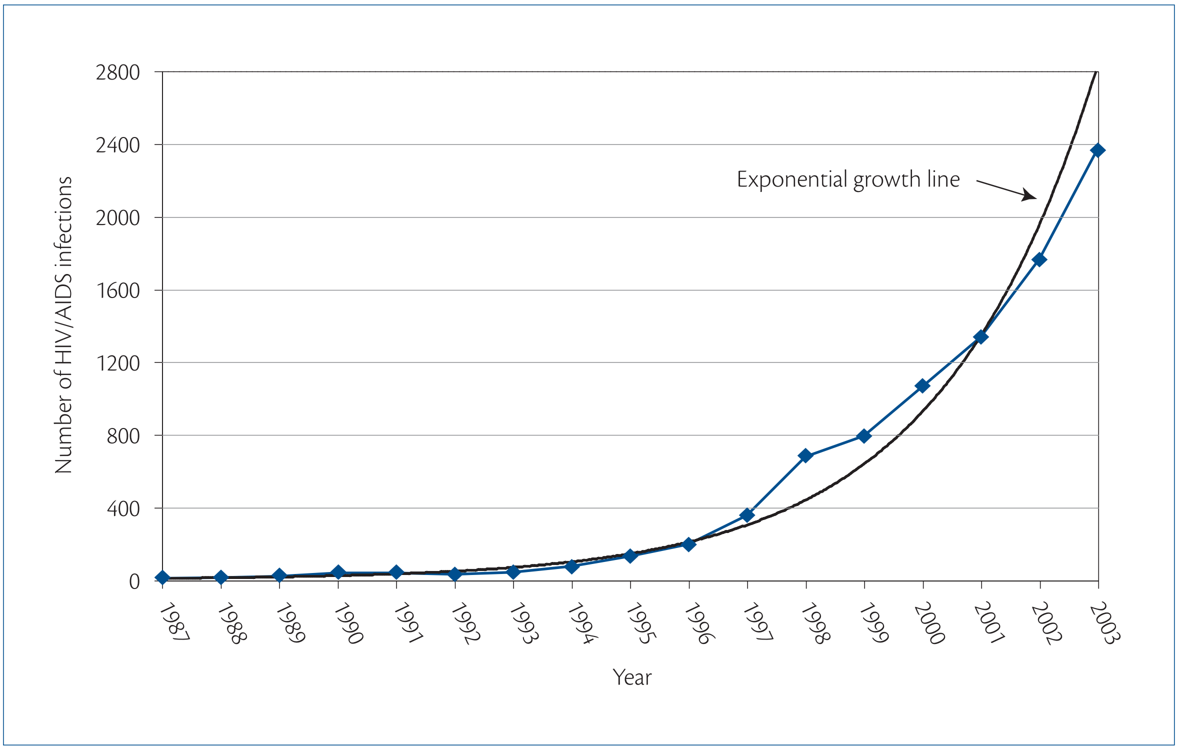


Figure 1.1.4 Number of reported HIV/AIDS infections in PNG, 1987–2003. Source: NACS (2003).

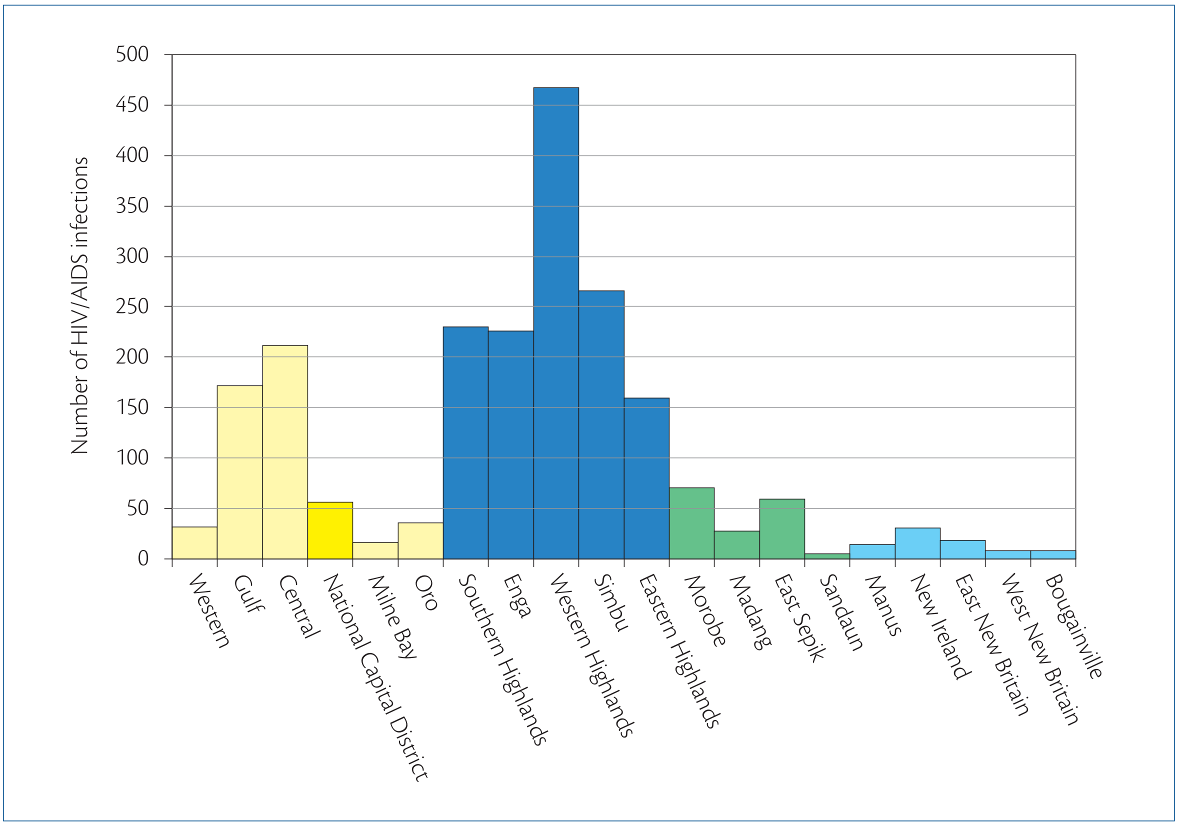


Figure 1.1.5 Number of detected HIV/AIDS infections by province of origin, 1987–2003. Source: NACS (2003).

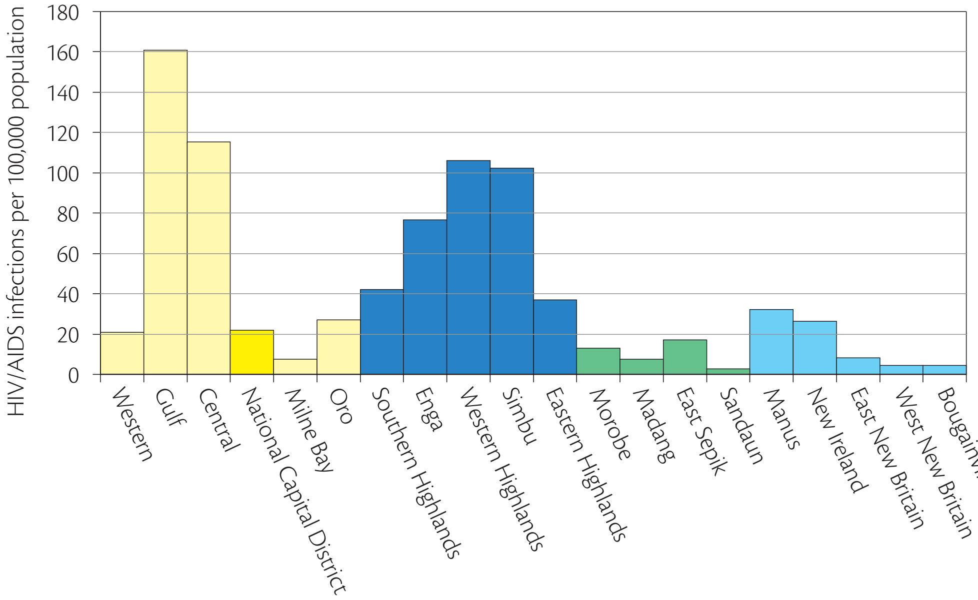


Figure 1.1.6 Rate of confirmed HIV/AIDS infections by province, 1987–2003. Source: NACS (2003).

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.

Sources

Allen, B. (1997). HIV/AIDS in rural Melanesia and South-East Asia: divination or description. In Linge, G. and Porter, D. (eds). *No Place for Borders: The HIV/AIDS Epidemic and Development in Asia and the Pacific*. Allen & Unwin, St Leonards, NSW. pp. 114–123.

Barnett, T. and Blaikie, P. (1992). *AIDS in Africa: Its Present and Future Impact*. Belhaven Press, London.

DNPM (Department of National Planning and Monitoring) (1999). *Papua New Guinea National Population Policy 2000–2010*. Department of National Planning and Monitoring, Port Moresby.

NACS (National AIDS Council Secretariat and Department of Health) (2003). HIV/AIDS quarterly report December 2003. National AIDS Council Secretariat and Department of Health, Boroko, Papua New Guinea.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

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		Anthropogenous (%)	Current use (%)
	(km²)	(%)		
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:

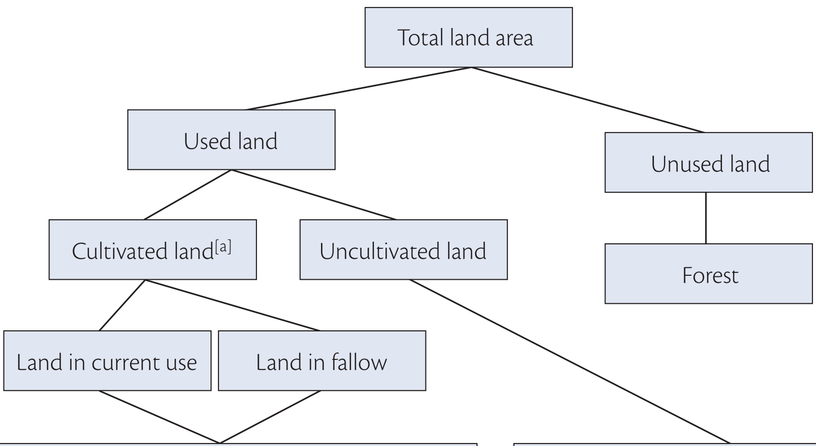
- 319 531 km^2, or about 70% of the total land area of PNG was unused (Table 1.2.1, Figure 1.2.2).
- Of the 140 323 km^2 of used land, 22 465 km^2 (5% of the total land area and 16% of used land) was uncultivated and was grassland, subalpine or alpine grassland, savanna woodland, or sago stands.
- A 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.

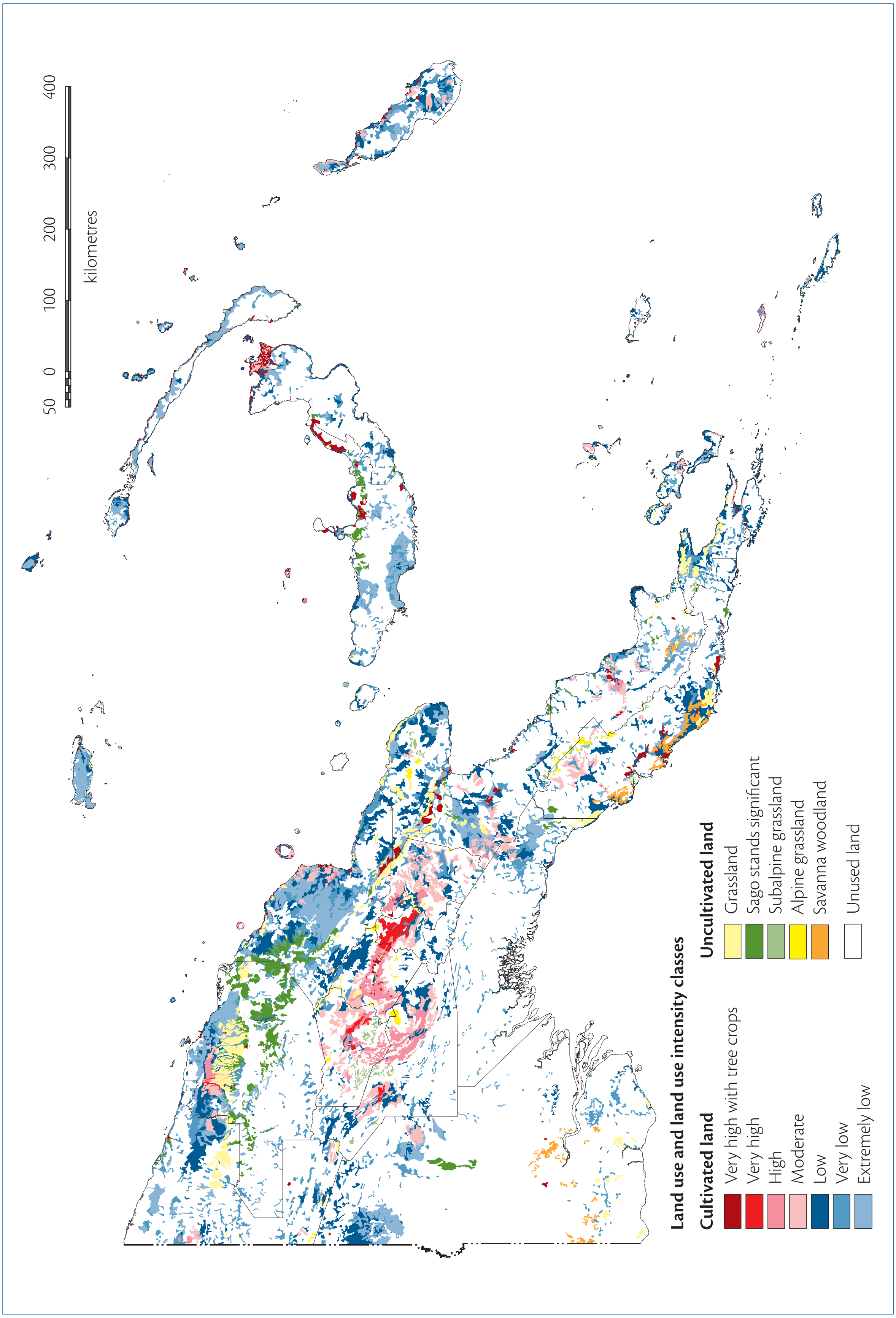


Figure 1.2.2 Land use and land use intensity from PNGRIS, 1975. Source: PNGRIS.

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 (%)
	(km²)	(%)	(km²)	(%)	
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.

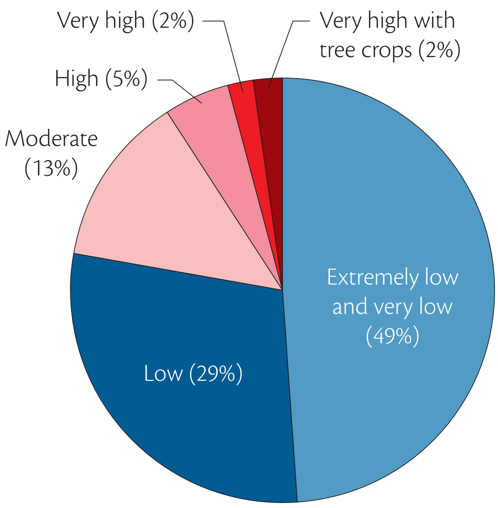


Figure 1.2.3 Proportion of cultivated land by PNGRIS land use intensity class, 1975 (km²). Source: PNGRIS.

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.

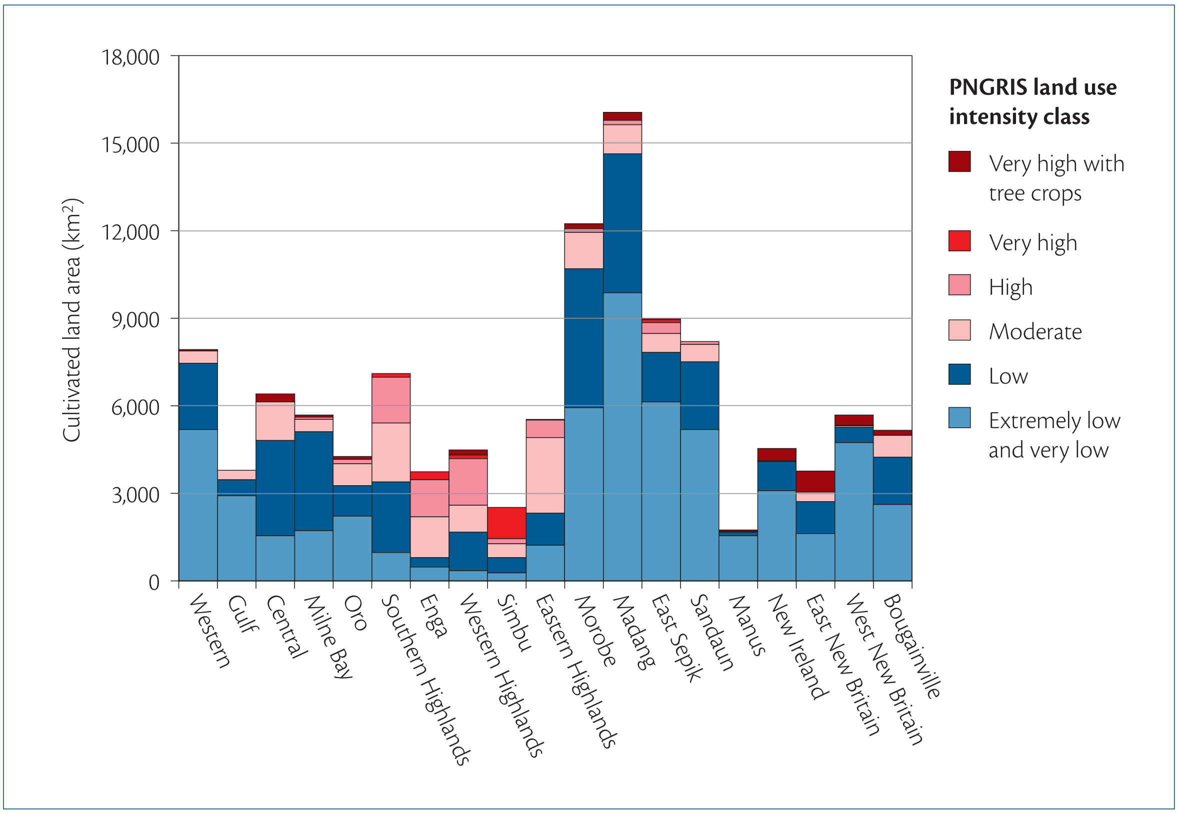


Figure 1.2.4 Cultivated land area by PNGRIS land use intensity class and province, 1975. Source: PNGRIS.

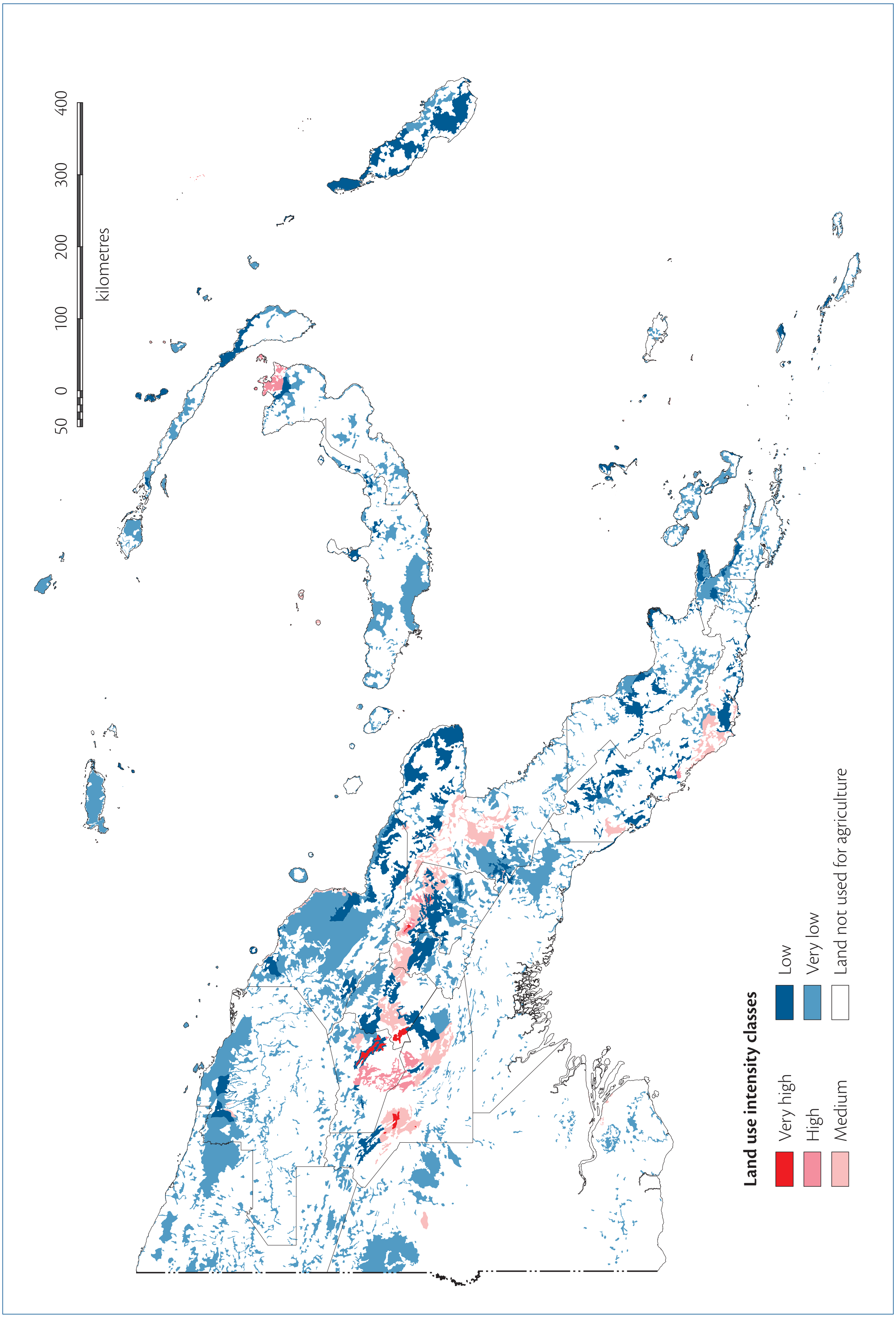


Figure 1.2.5 Land use intensity (R-value) from MASP, 1995. Source: MASP.

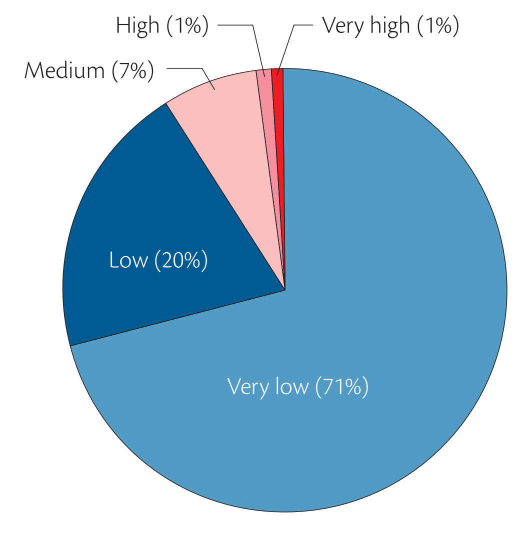


Figure 1.2.6 Proportion of cultivated land by MASP land use intensity class (R-value), 1995 (km²). Source: MASP.

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.

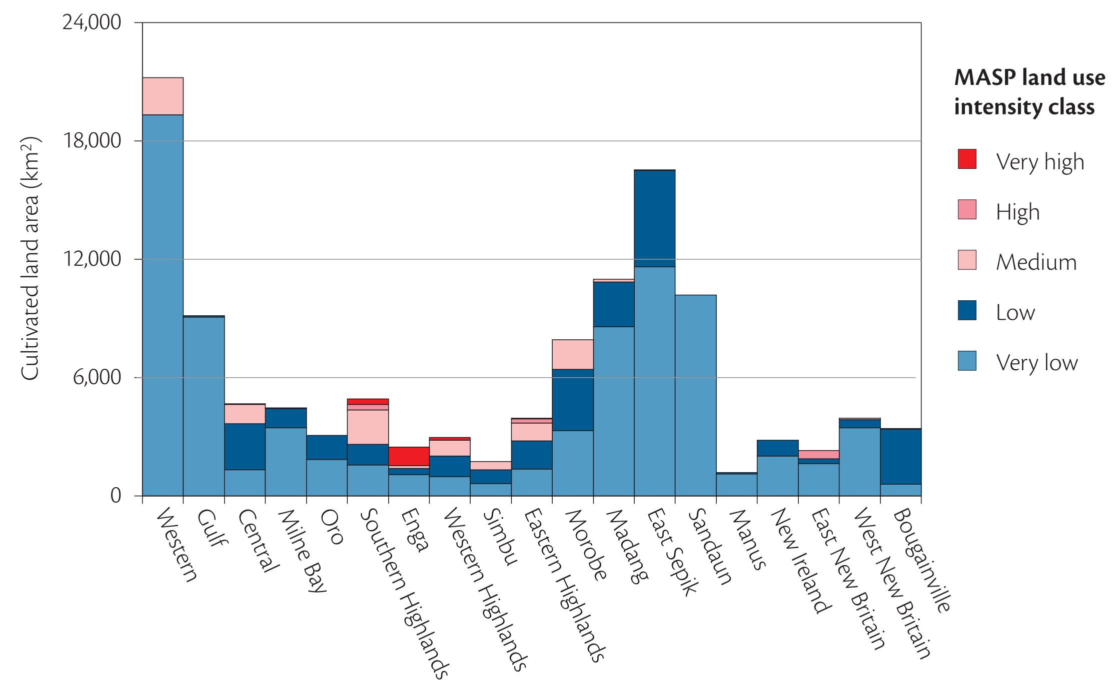


Figure 1.2.7 Cultivated land area by MASP land use intensity class (R-value) and province, 1995. Source: MASP.

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).

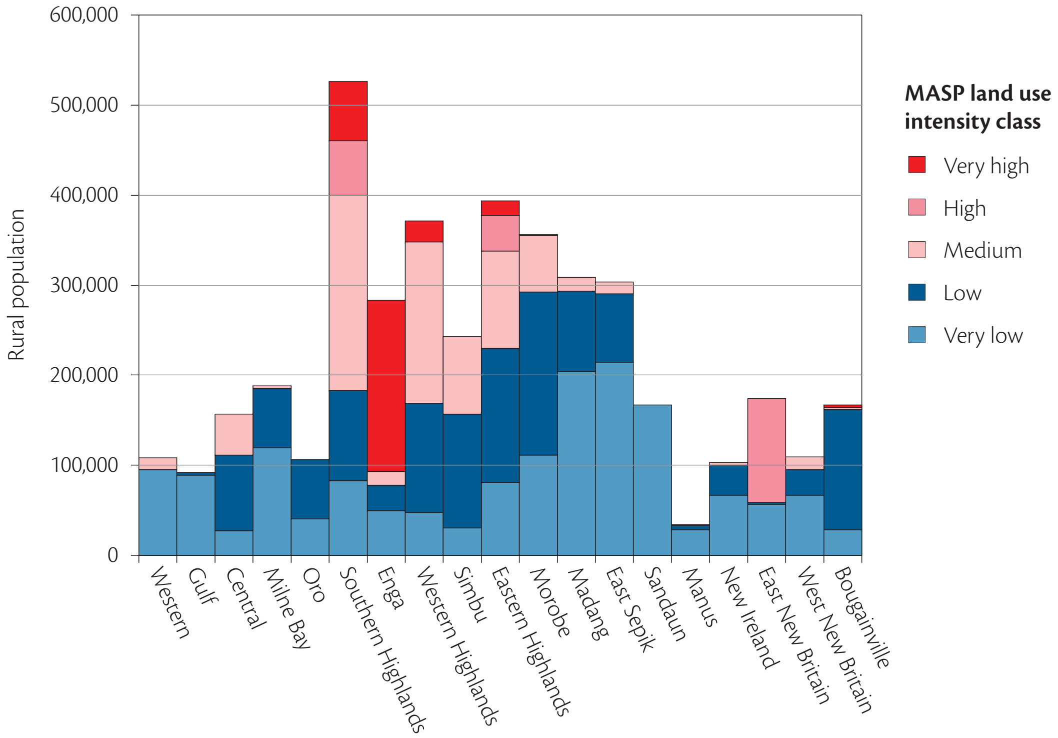


Figure 1.2.8 Number of rural people living on cultivated land by MASP land use intensity class (R-value) and province. Sources: NSO (2002); MASP.

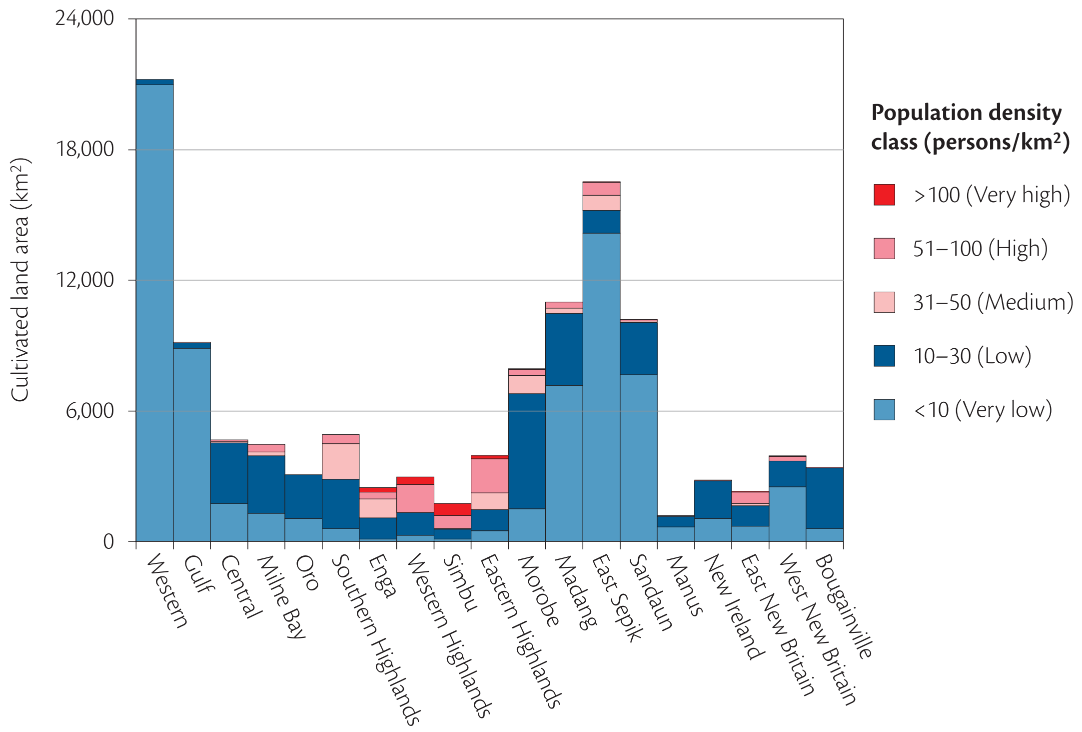


Figure 1.2.9 Cultivated land area by population density class and province, 1995. Sources: NSO (2002); MASP.

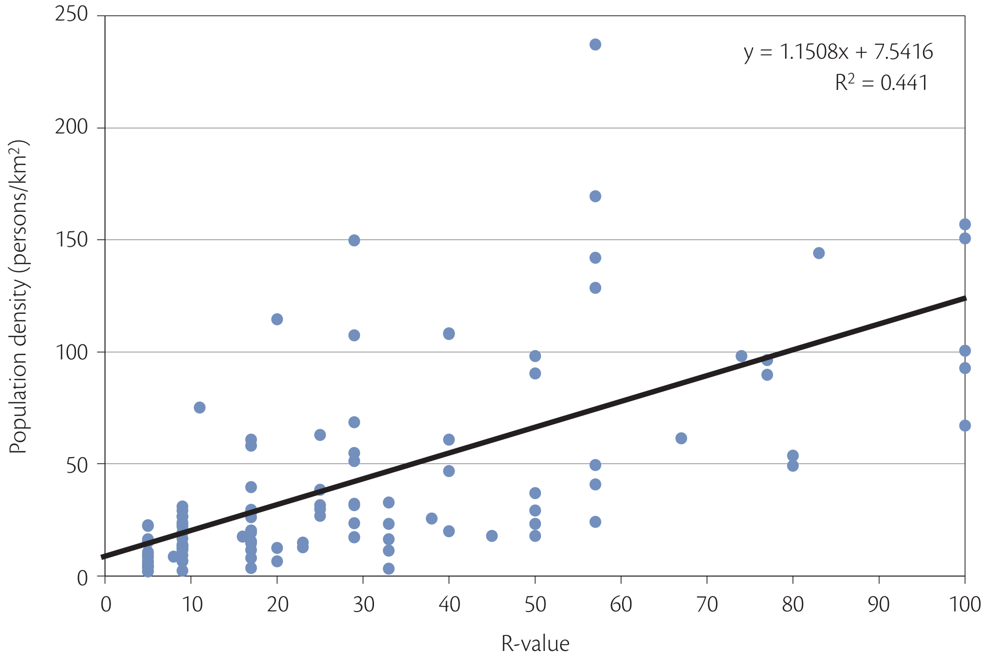


Figure 1.2.10 Association between MASP land use intensity (R-value) and population density, 1995.
Sources: NSO (2002); MASP.

Furthermore, if the area of 'agricultural land' in PNG was only 760 km^2, 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.

Sources

Allen, B.J. (2001). Boserup and Brookfield and the association between population density and agricultural intensity in Papua New Guinea. *Agricultural Transformation and Intensification. Asia Pacific Viewpoint Special Issue* 42(2/3):237–254.

Bellamy, J.A. (1986). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Natural Resources Series No. 6. Division of Water and Land Resources, Commonwealth Scientific and Industrial Research Organisation, Canberra.

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Second edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

Bourke, R.M. (2001). Intensification of agricultural systems in Papua New Guinea. *Agricultural Transformation and Intensification. Asia Pacific Viewpoint Special Issue* 42(2/3):219–235.

Bourke, R.M., Allen, B.J., Hobsbawn, P. and Conway, J. (1998). *Papua New Guinea: Text Summaries*. Agricultural Systems of Papua New Guinea Working Paper No. 1. Two volumes. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Food and Agriculture Organization of the United Nations website. PNG land use information can be found at <http://faostat.fao.org/>.

McAlpine, J.R. and Freyne, D.F. (2001). Land use change and intensification in Papua New Guinea 1975–1996. *Agricultural Transformation and Intensification. Asia Pacific Viewpoint Special Issue* 42(2/3):209–218.

McAlpine, J.R., Freyne, D.F. and Keig, G. (2001). Land use and rural population change in PNG, 1975–96. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 277–283.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

Ruthenberg, H. (1980). *Farming Systems in the Tropics*. Third edition. Clarendon Press, Oxford.

Sauer, C.O. (1952). *Agricultural Origins and Dispersals*. Bowman Memorial Lectures Series 2. American Geographical Society, New York.

Saunders, J.C. (1993). *Agricultural Land Use of Papua New Guinea: Explanatory Notes to Map.* PNGRIS Publication No. 1. Australian International Development Assistance Bureau, Canberra.

[3] 4.2 million people ÷ 760 km^2 = 5526 persons/km^2.

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.

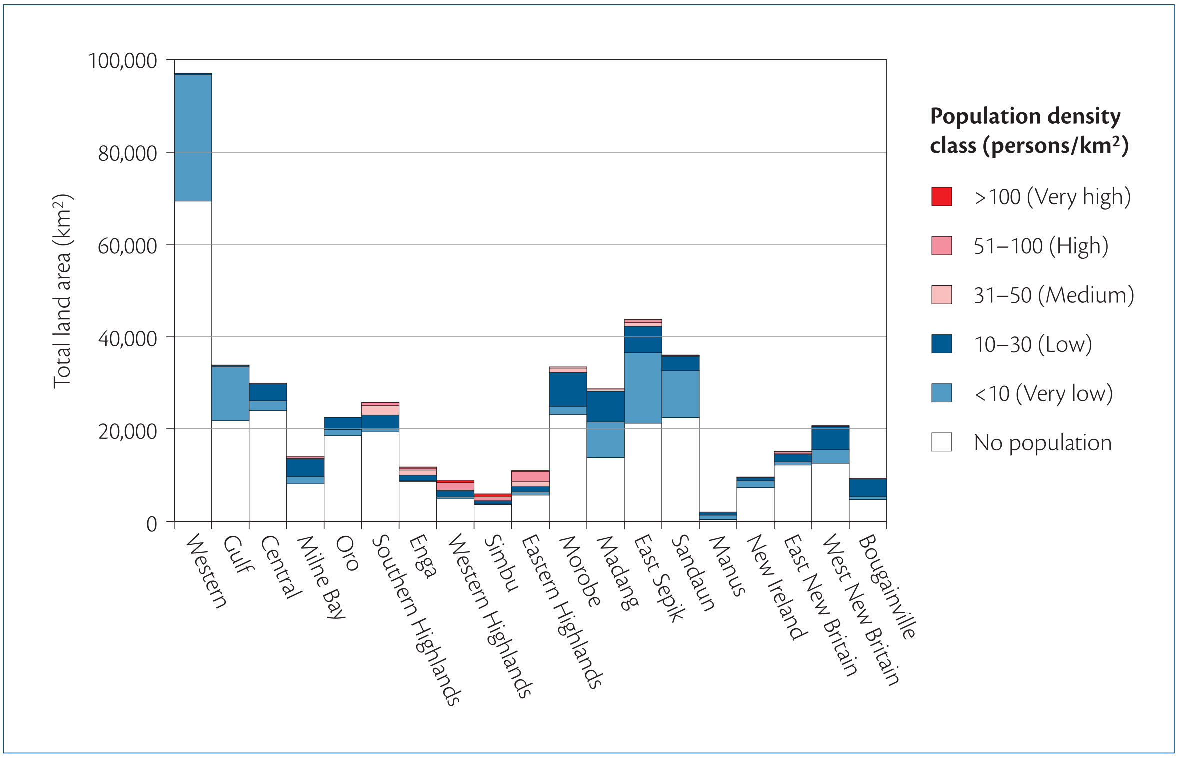


Figure 1.3.1 Total land area by population density class and province. Sources: McAlpine and Quigley (c. 1995); NSO (2002); MASP.

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] (km²)	Population density (persons/km²)
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.

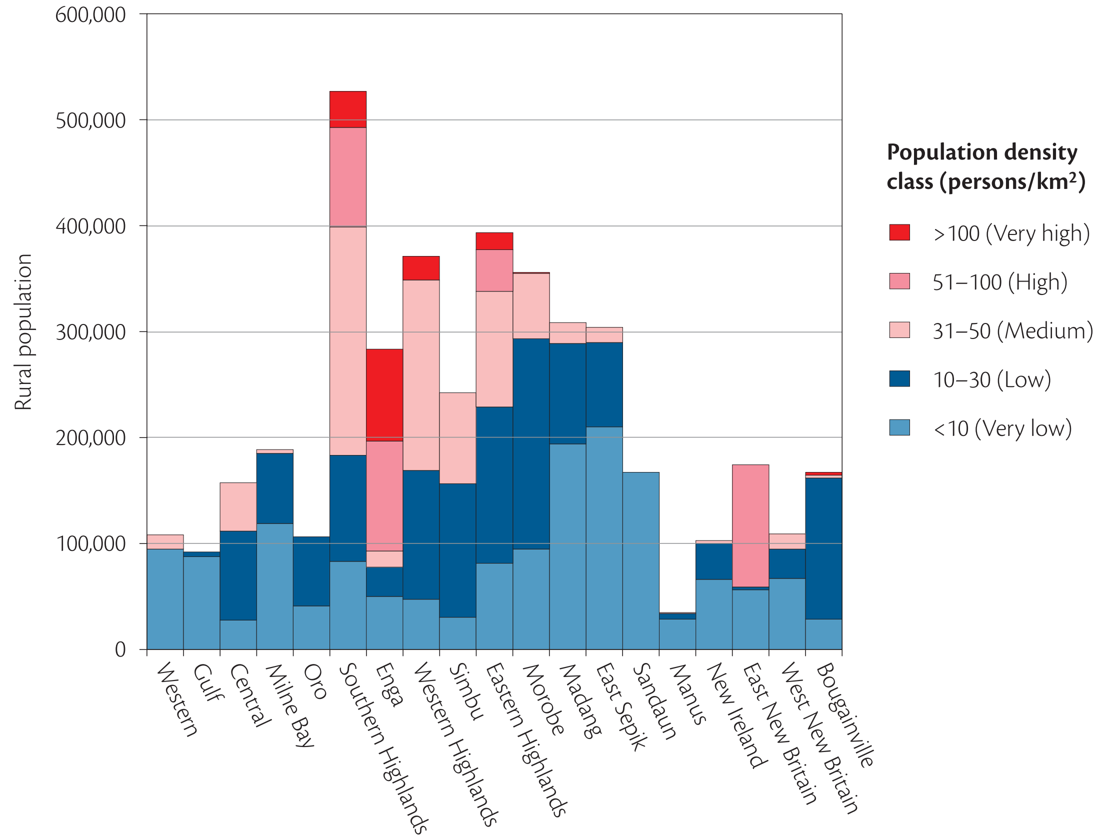


Figure 1.3.2 Rural population by population density class and province. Sources: NSO (2002); MASP.

Sources

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Second edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

Bourke, R.M., Allen, B.J., Hobsbawn, P. and Conway, J. (1998). *Papua New Guinea: Text Summaries*. Agricultural Systems of Papua New Guinea Working Paper No. 1. Two volumes. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Bourke, R.M. and Betitis, T. (2003). Sustainability of agriculture in Bougainville Province, Papua New Guinea. Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Foale, S. (2005). *Sharks, sea slugs and skirmishes: managing marine and agricultural resources on small, overpopulated islands in Milne Bay, PNG*. Resource Management in Asia-Pacific Working Paper No. 64. Resource Management in Asia-Pacific Program, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

McAlpine, J. and Quigley, J. (c. 1995). *Natural Resources, Land Use and Population Distribution of Papua New Guinea: Summary Statistics from PNGRIS*. PNGRIS Report No. 7. Australian Agency for International Development, Canberra.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

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:

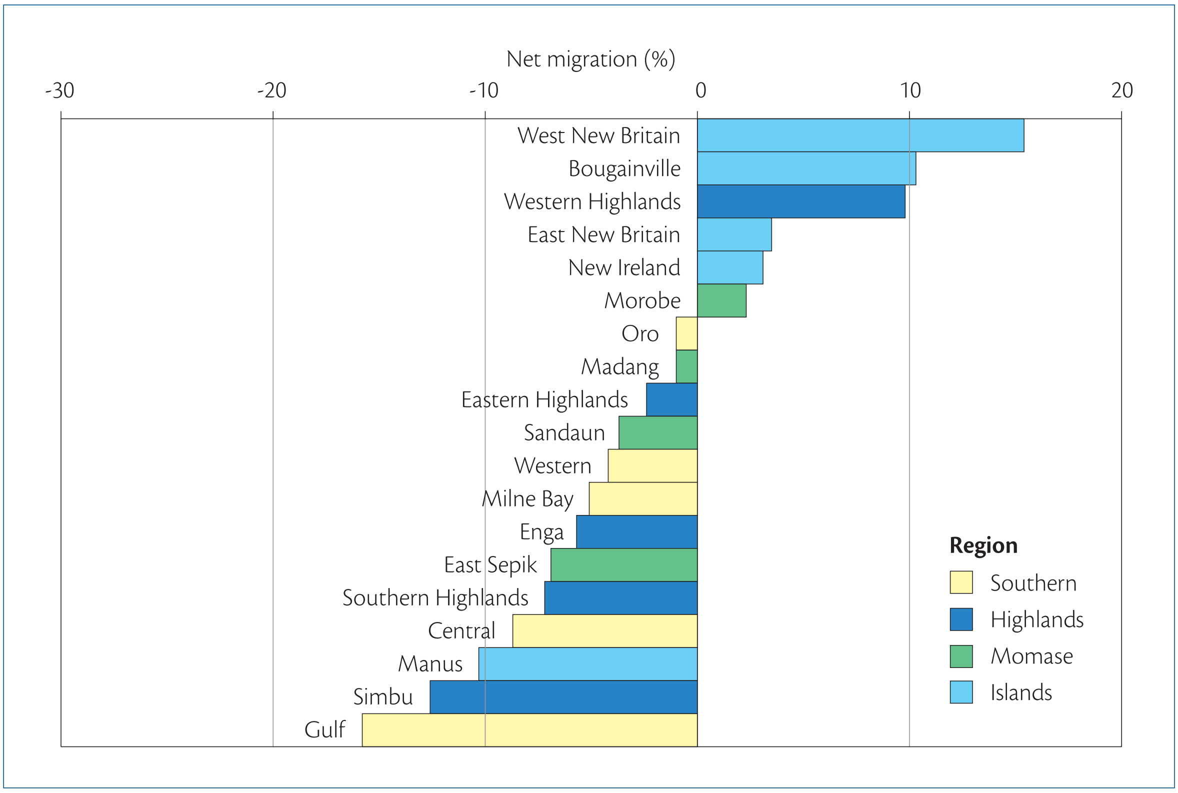


Figure 1.4.1 Net migration by province, 1980. Source: Goodman et al. (1985).

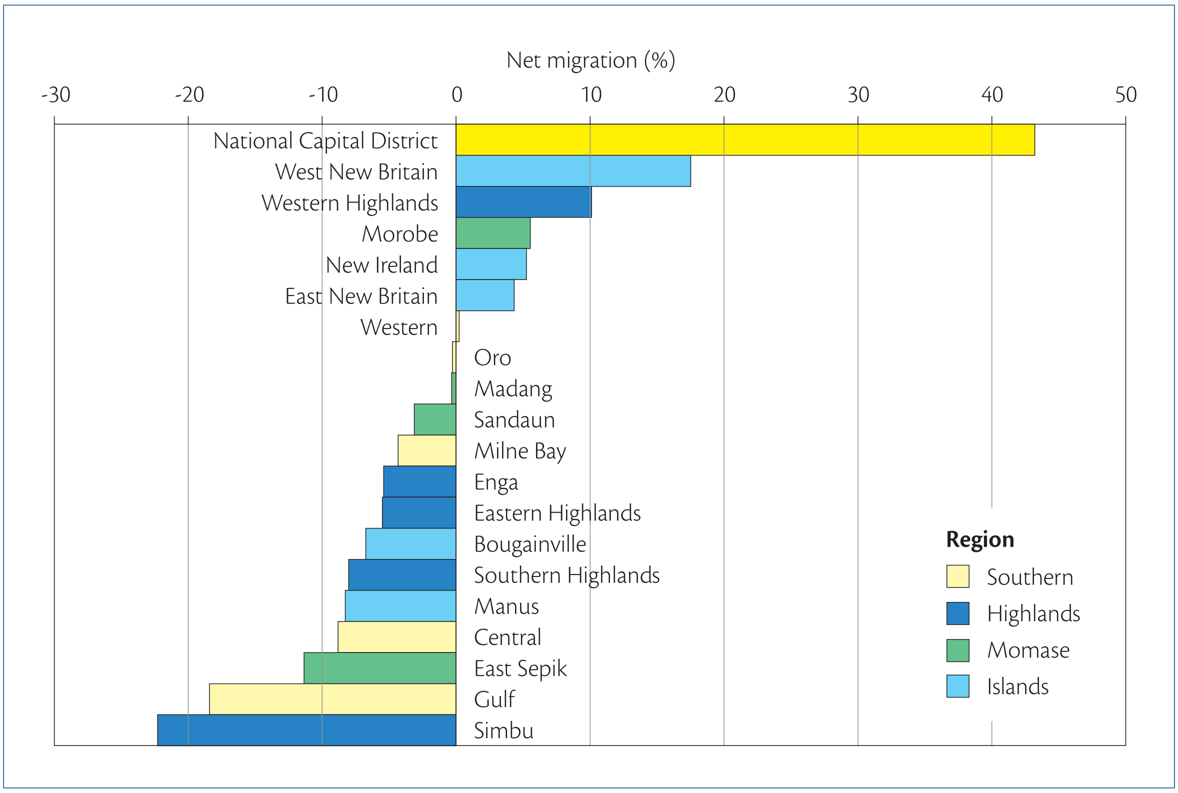


Figure 1.4.2 Net migration by province, 1990. Source: DNPM (1999).

- **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.

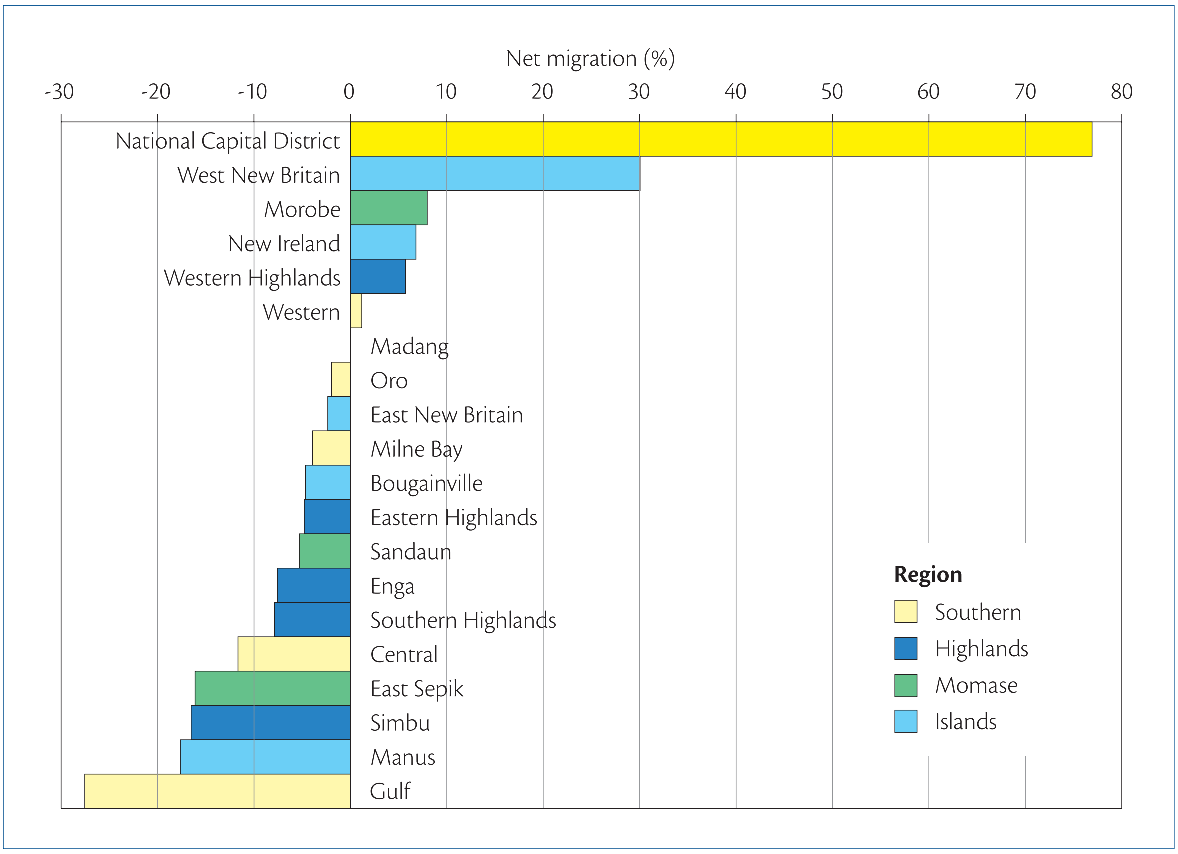


Figure 1.4.3 Net household migration by province, 2000. **Note:** This figure differs from Figures 1.4.1 and 1.4.2 in that it is based on the place of birth and the residence of household heads at the 2000 census, and not of individuals. The proportions are of the total number of households, not the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

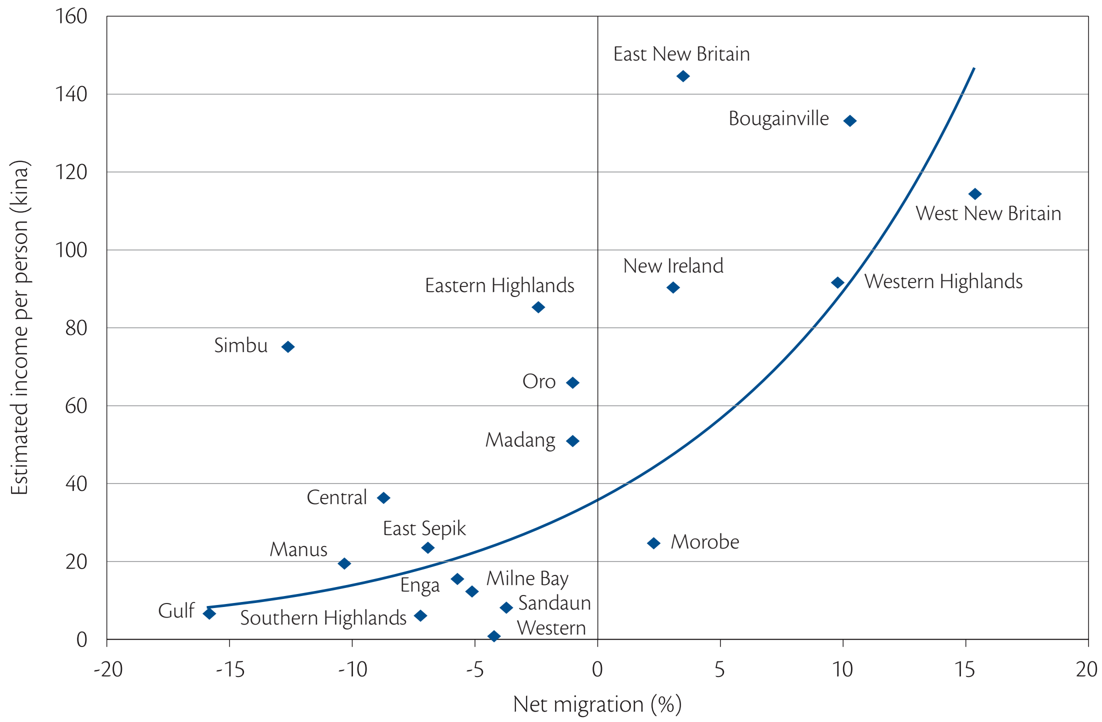


Figure 1.4.4 Association between net migration, 1980, and estimated cash income per person, 1985.
Source: Goodman et al. (1985).

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.

Sources

DNPM (Department of National Planning and Monitoring) (1999). *Papua New Guinea National Population Policy 2000–2010*. Department of National Planning and Monitoring, Port Moresby.

Goodman, R., Lepani, C. and Morawetz, D. (1985). *The Economy of Papua New Guinea: An Independent Review*. Development Studies Centre, The Australian National University, Canberra.

Keig, G. (2001). Rural population growth in Papua New Guinea between 1980 and 1990. *Agricultural Transformation and Intensification. Asia Pacific Viewpoint Special Issue* 42(2/3):255–268.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

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.

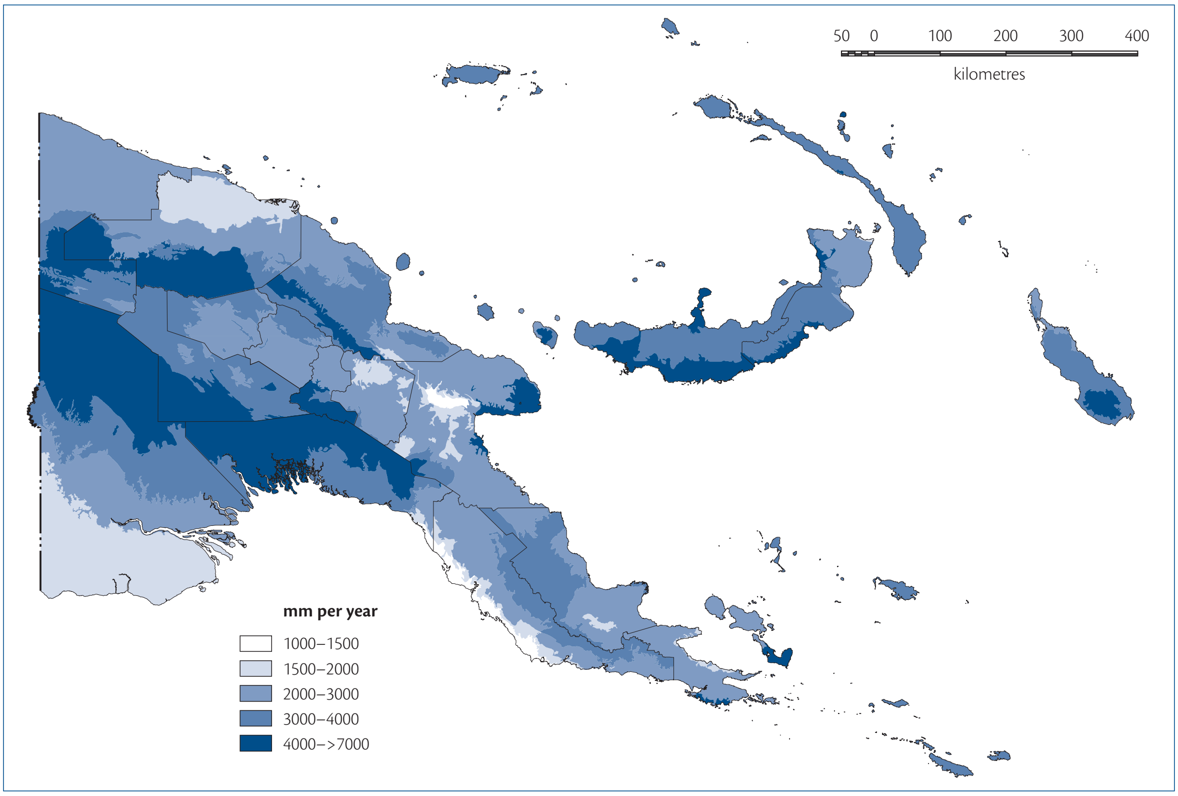


Figure 1.5.1 Annual rainfall from PNGRIS. Source: PNGRIS.

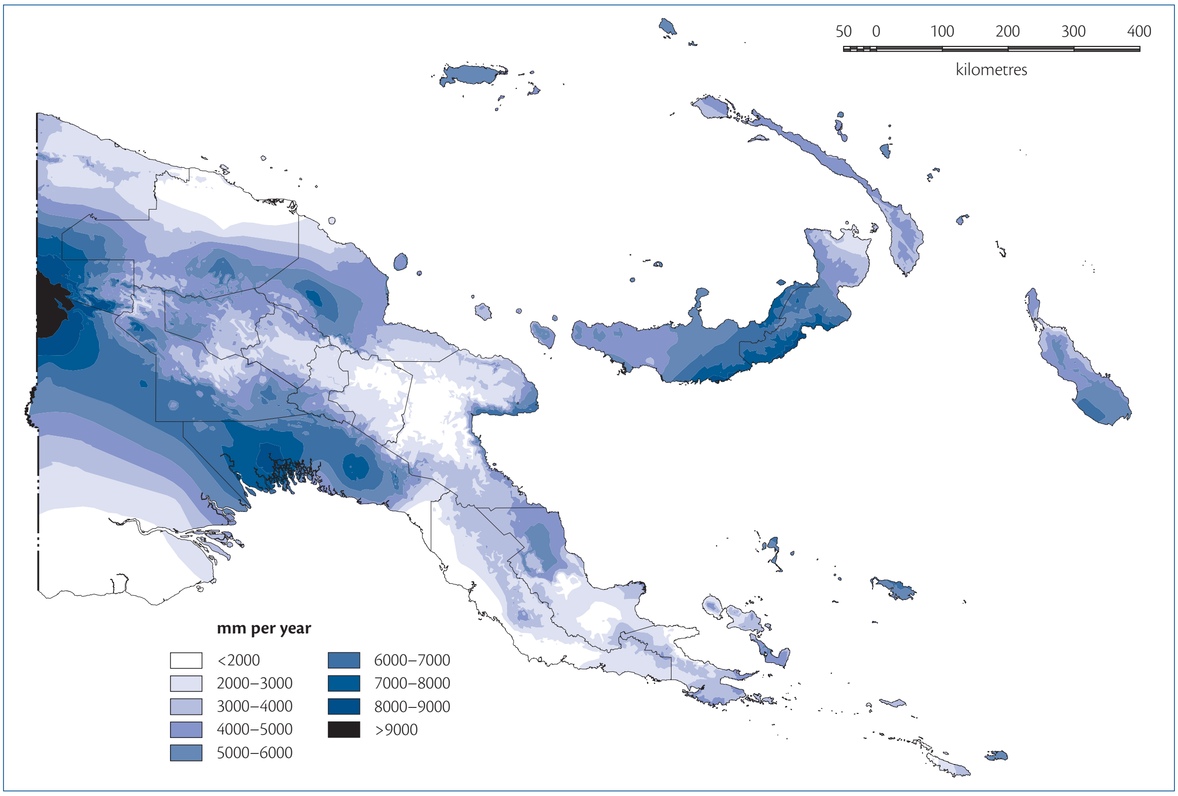


Figure 1.5.2 Annual rainfall from CRES. Source: Centre for Resource and Environmental Science, ANU.

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.

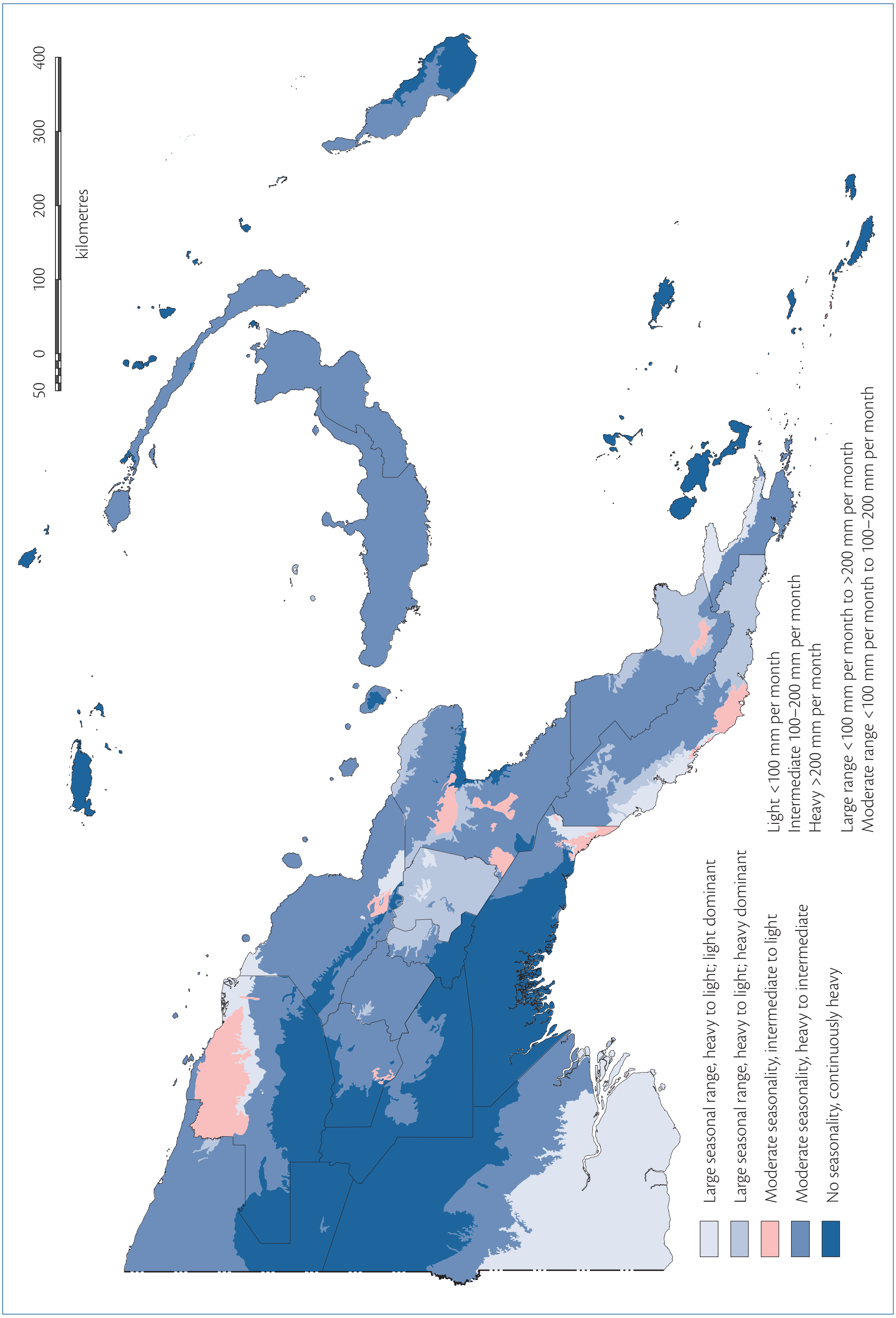


Figure 1.5.3 Rainfall seasonality. Source: PNGRIS.

- 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.

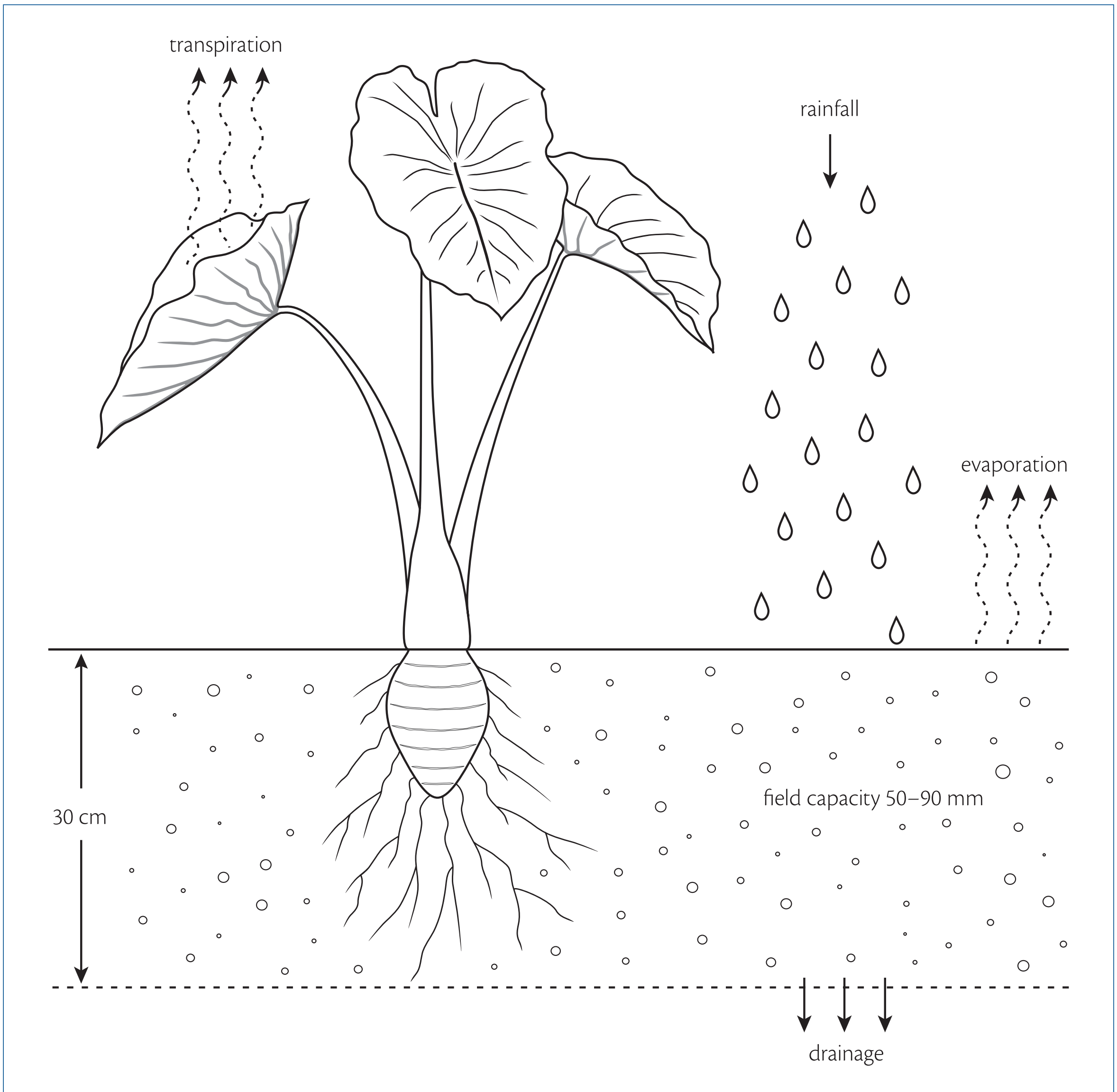


Figure 1.5.4 Water cycle and soil field capacity. Drawing by Catherine Eadie.

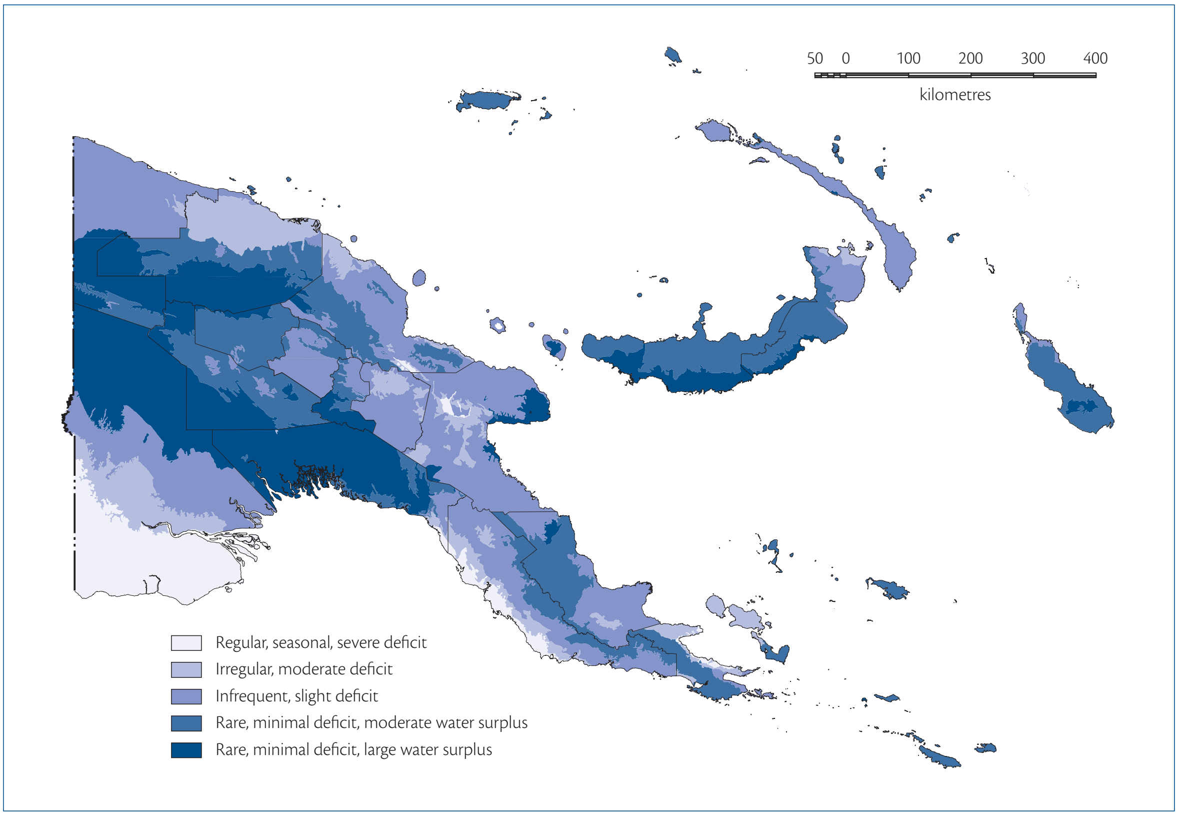


Figure 1.5.5 Soil water deficit and surplus. Source: PNGRIS.

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.

Sources

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Second edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

McAlpine, J.R., Keig, G. and Short, K. (1975). *Climatic tables for Papua New Guinea*. Division of Land Use Research Technical Paper No. 37. Commonwealth Scientific and Industrial Research Organisation, Melbourne.

McAlpine, J.R., Keig, G. and Falls, R. (1983). *Climate of Papua New Guinea*. Commonwealth Scientific and Industrial Research Organisation in association with Australian National University Press, Canberra.

Radcliffe, D.J. (1984). *The land resources of Upper Mendi*. AFTSEMU Technical Report No. 8. Agricultural Field Trials, Studies, Extension and Monitoring Unit, Southern Highlands Rural Development Project, Mendi.

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: widespread droughts, repeated frosts in the highlands, severe food shortages, forest fires, and migrations (of people from areas with inadequate food).

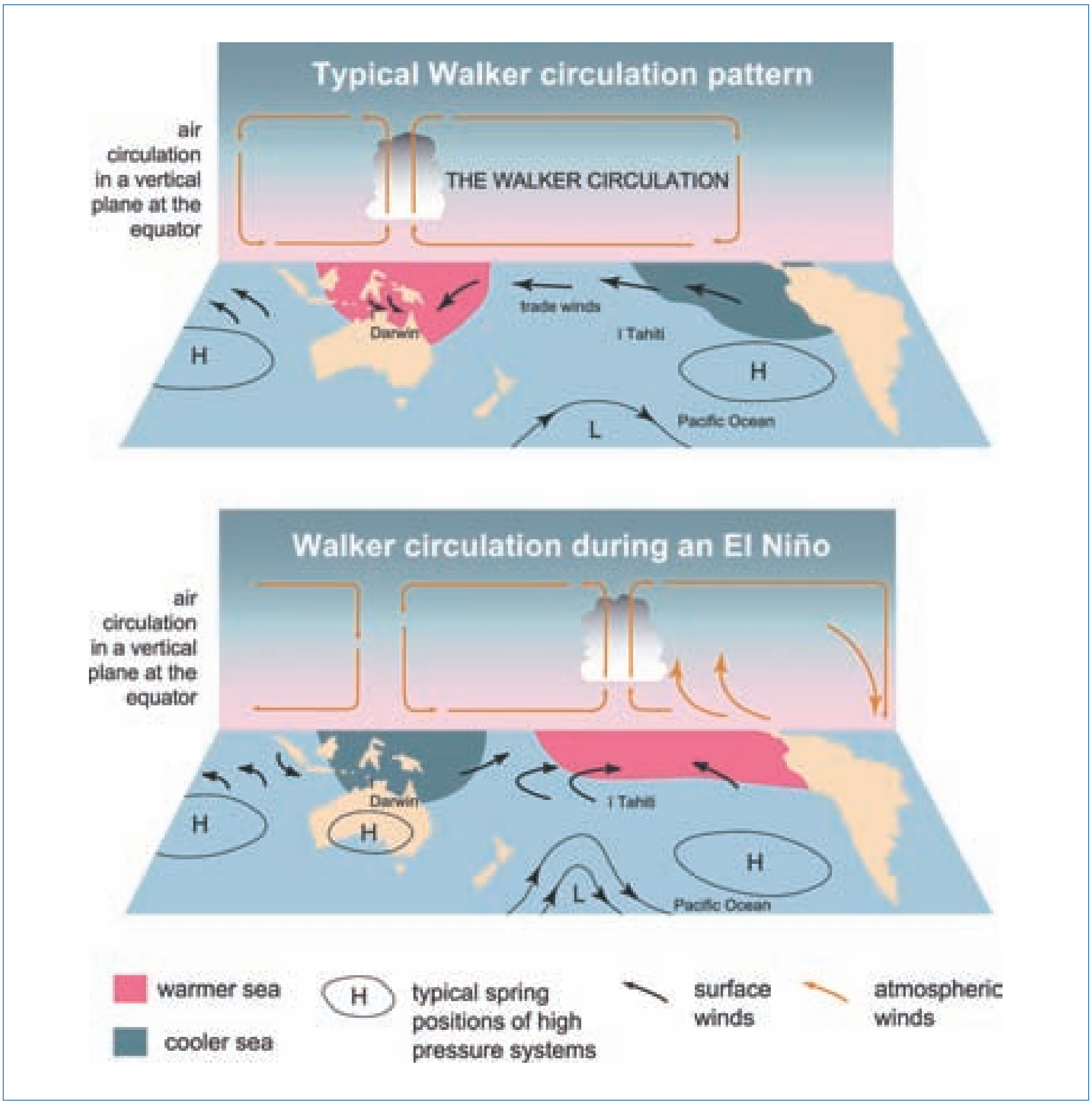


Figure 1.6.1 The circulation of air over the Pacific Ocean and the Southern Oscillation.

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.

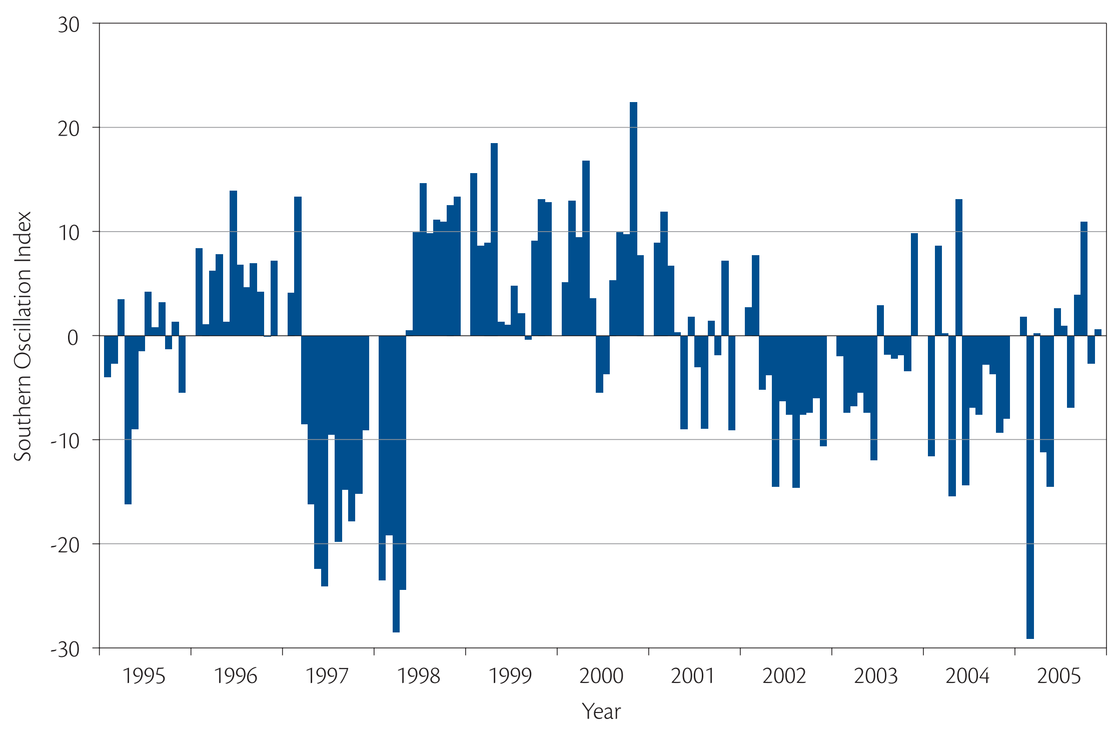


Figure 1.6.2 The Southern Oscillation Index, 1995–2005. Source: Australian Government Bureau of Meteorology website. Data available at <ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/soiplaintext.html>.

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.

Sources

Allen, B.J. and Bourke, R.M. (2001). The 1997 drought and frost in PNG: overview and policy implications. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference.* ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 155–163.

Allen, B., Brookfield, H. and Byron, Y. (eds) (1989). Frost and Drought in the Highlands of Papua New Guinea: A Special Collection of Papers. *Mountain Research and Development*. 9(3):199–334.

Australian Government Bureau of Meteorology website <http://www.bom.gov.au/climate/glossary/elnino/elnino.shtml>.

Bang, S.K. and Sitango, K. (2002). Indigenous drought coping strategies and risk management in Papua New Guinea. In Yokoyama, S. and Concepcion, R.N. (eds). *Coping against El Niño for Stabilizing Rainfed Agriculture: Lessons from Asia and the Pacific. Proceedings of a Joint Workshop held in Cebu, the Philippines*. CGPRT Centre Monograph No. 43. CGPRT Centre, Bogor, Indonesia. pp. 147–163.

Bang, S.K., Poloma, S. and Allen, B. (2003). *Stabilization of Upland Agriculture Under El Niño-Induced Climatic Risk: Impact Assessment and Mitigation Measures in Papua New Guinea*. CGPRT Centre Working Paper No. 73. CGPRT Centre, Bogor, Indonesia.

Barter, P. (2001). Responses to the 1997–98 drought in PNG. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference.* ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 260–264.

Bourke, R.M. (2000). Impact of the 1997 drought and frosts in Papua New Guinea. In Grove, R.H. and Chappell, J. (eds). *El Niño – History and Crisis: Studies from the Asia-Pacific Region*. The White Horse Press, Cambridge. pp. 149–170.

Bourke, R.M. (2005). How Papua New Guinea villagers survived the 1997 drought and frosts. *Development Bulletin* (67):27–29.

Kapal, D., Bang, S., Askin, D. and Allen, B. (eds) (2003). *Drought Response: On-Farm Coping Strategies*. NARI Information Bulletin No. 6. National Agricultural Research Institute, Lae.

Sudradjat, A. (2001). Australia's response to the 1997 PNG drought. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 218–221.

Whitecross, N. and Franklin, P. (2001). The role of rice in the 1997 PNG drought. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference.* ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 255–259.

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

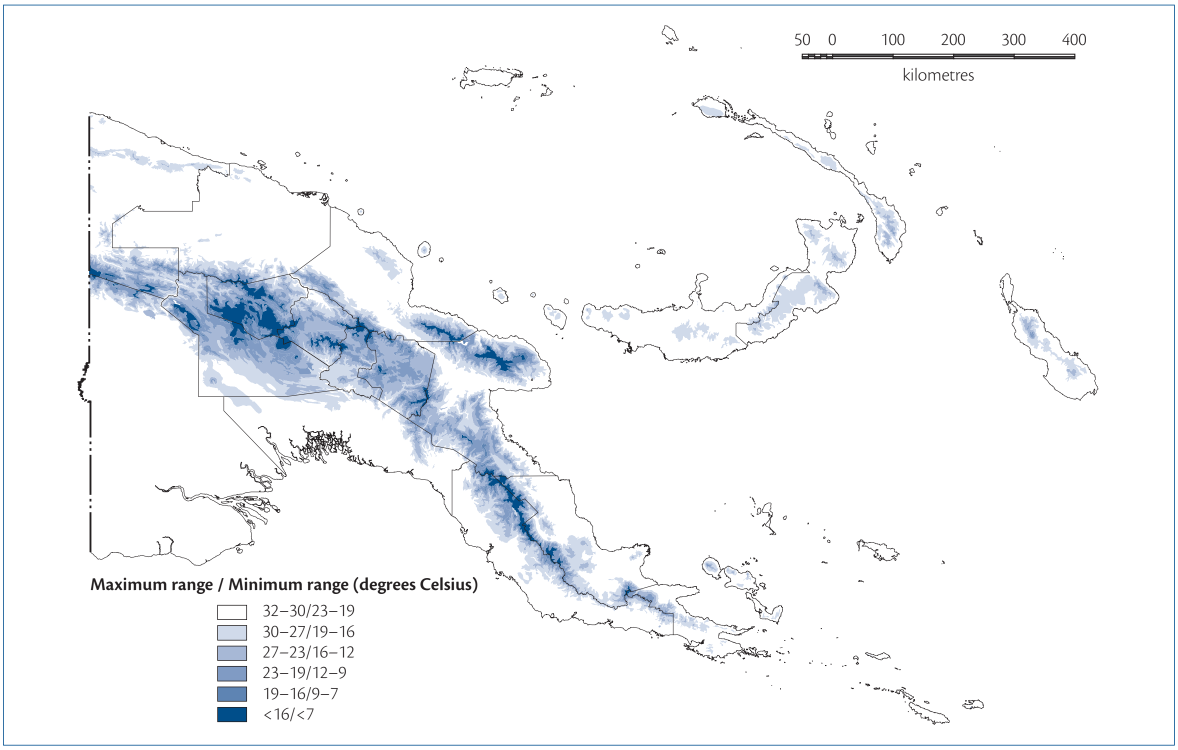


Figure 1.7.1 Generalised temperature zones in PNG in January, based on lapse rates and altitude (°C) (July temperatures are less than 3 °C lower). Sources: McAlpine et al. (1983:95); PNGRIS.

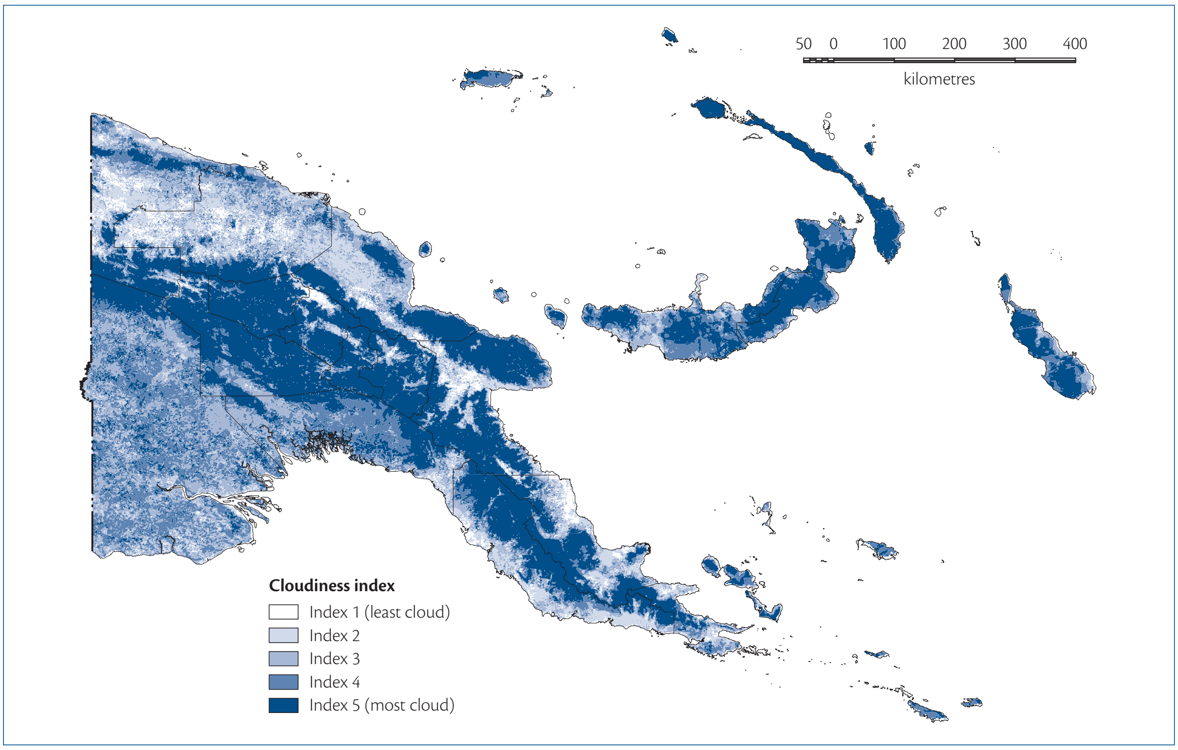


Figure 1.7.2 Cloud cover over PNG, 1997–1998. Source: Developed from a composite set of Advanced Very High Resolution Radiometer (AVHRR) satellite images for twelve months in 1997 and 1998, provided by the CSIRO Division of Land and Water.

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.

Sources

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Second edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

McAlpine, J.R., Keig, G. and Falls, R. (1983). *Climate of Papua New Guinea*. Commonwealth Scientific and Industrial Research Organisation in association with Australian National University Press, Canberra.

McVicar, T.R. and Bierwirth, P.N. (2001). Rapidly assessing the 1997 drought in Papua New Guinea using composite AVHRR imagery. *International Journal of Remote Sensing* 22(11):2109–2128.

[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).

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

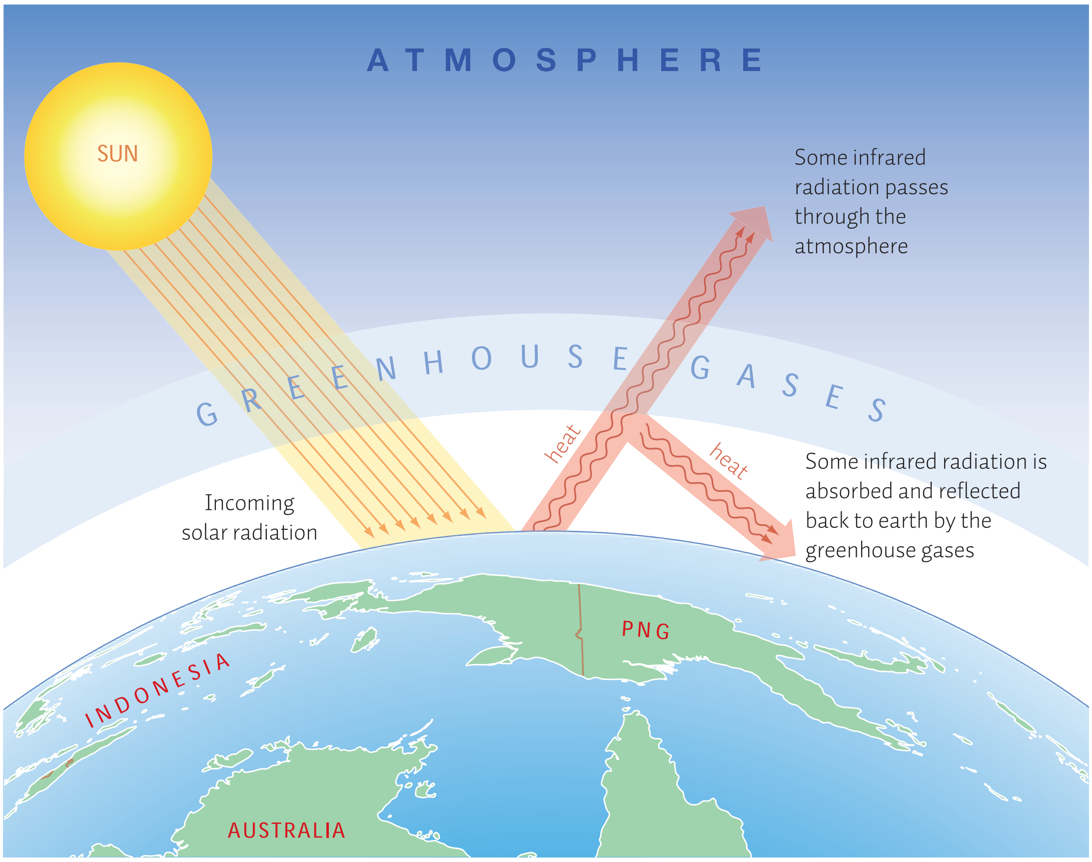


Figure 1.8.1 The greenhouse effect. Source: Cartographic Services, ANU.

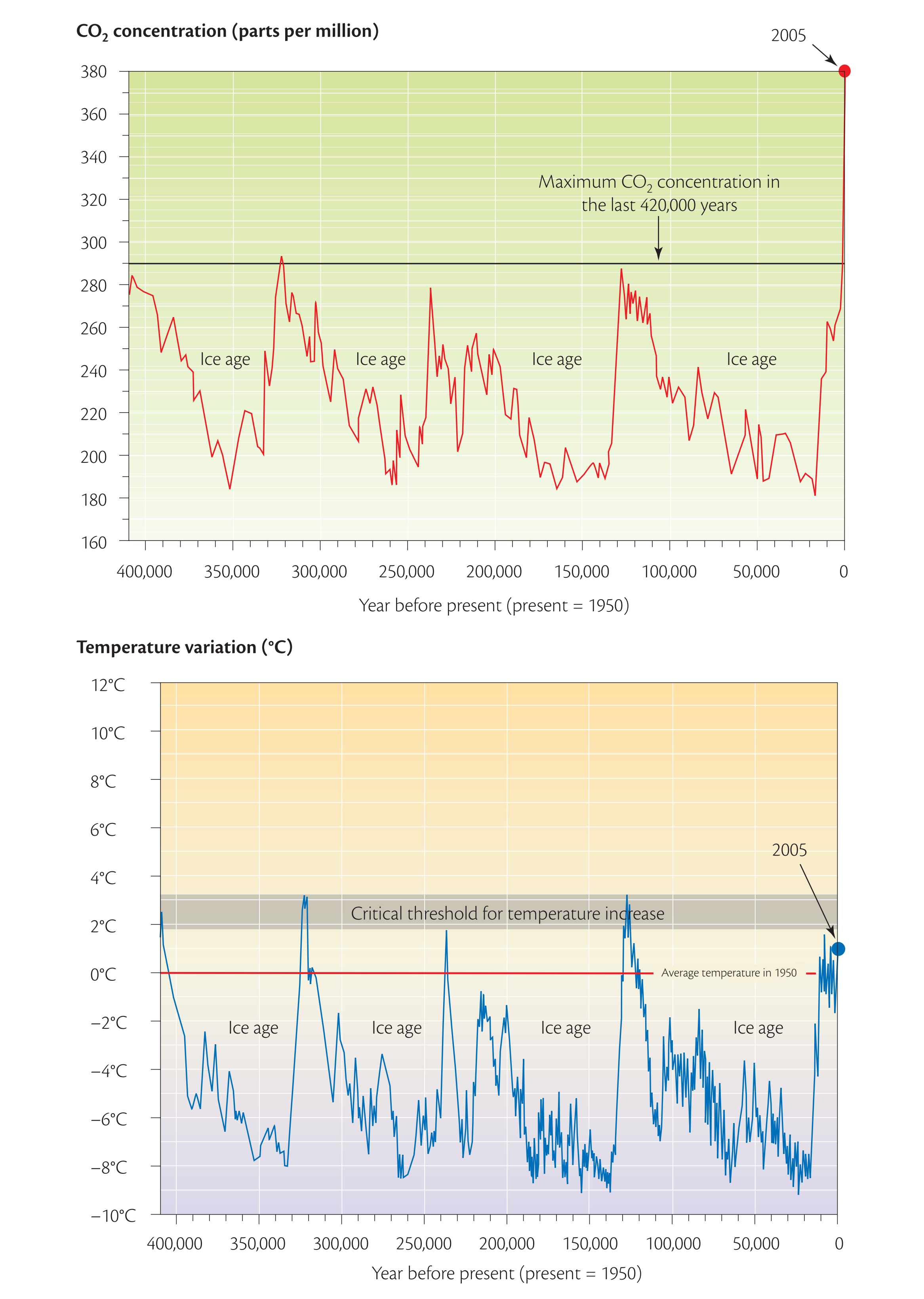


Figure 1.8.2 Record of carbon dioxide concentrations and average global temperature over the past 400 000 years.
Sources: UNEP/GRID-Arendal (2006) and <http://monde-diplomatique.fr/cartes> from data in Petit et al. (1999). Graphic design: Philippe Rekacewicz.

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

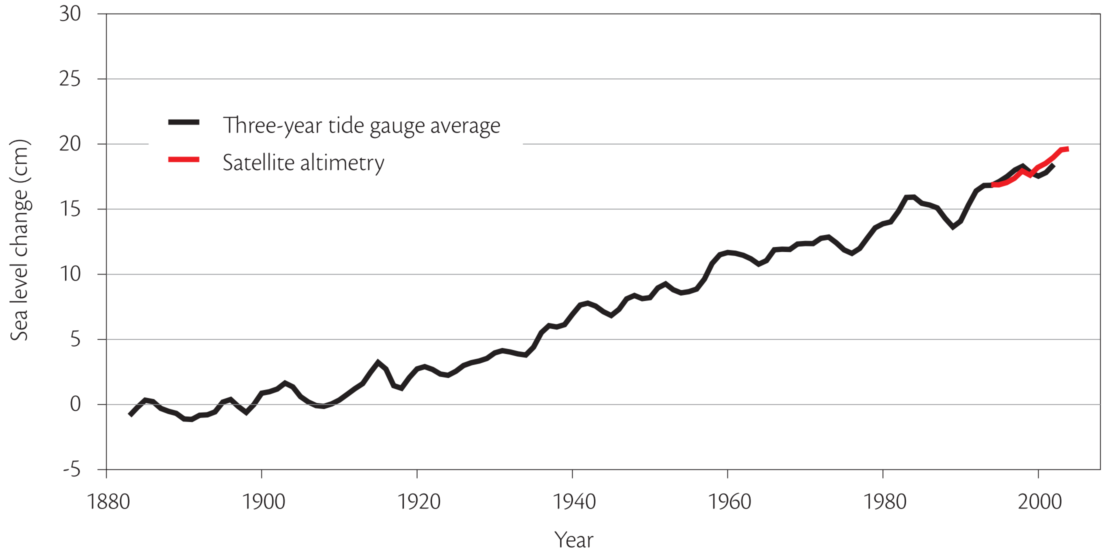


Figure 1.8.3 Global mean sea level rise, 1883–2002. **Note:** The tide gauge data spans 1883–2002 and the satellite altimetry data spans 1993–2004. Source: Robert A. Rohde / <http://www.globalwarmingart.com/>.

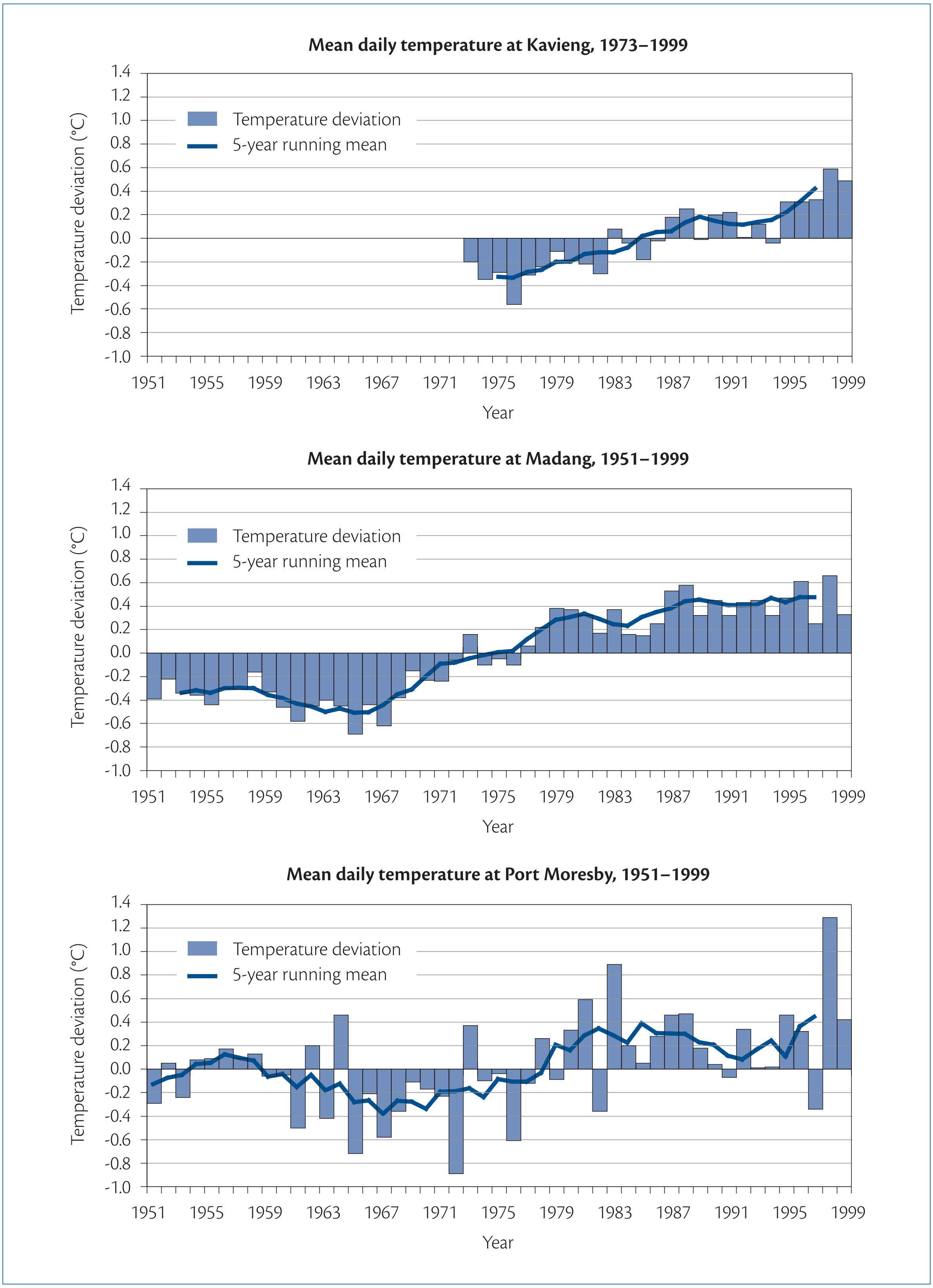


Figure 1.8.4 Temperature increases at Kavieng (1973–1999), Madang (1951–1999) and Port Moresby (1951–1999).
Note: Temperature deviation is the difference between the mean temperature for any one year from the long-term average for the entire period. Temperature data for Kavieng for the years 1951–1972 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

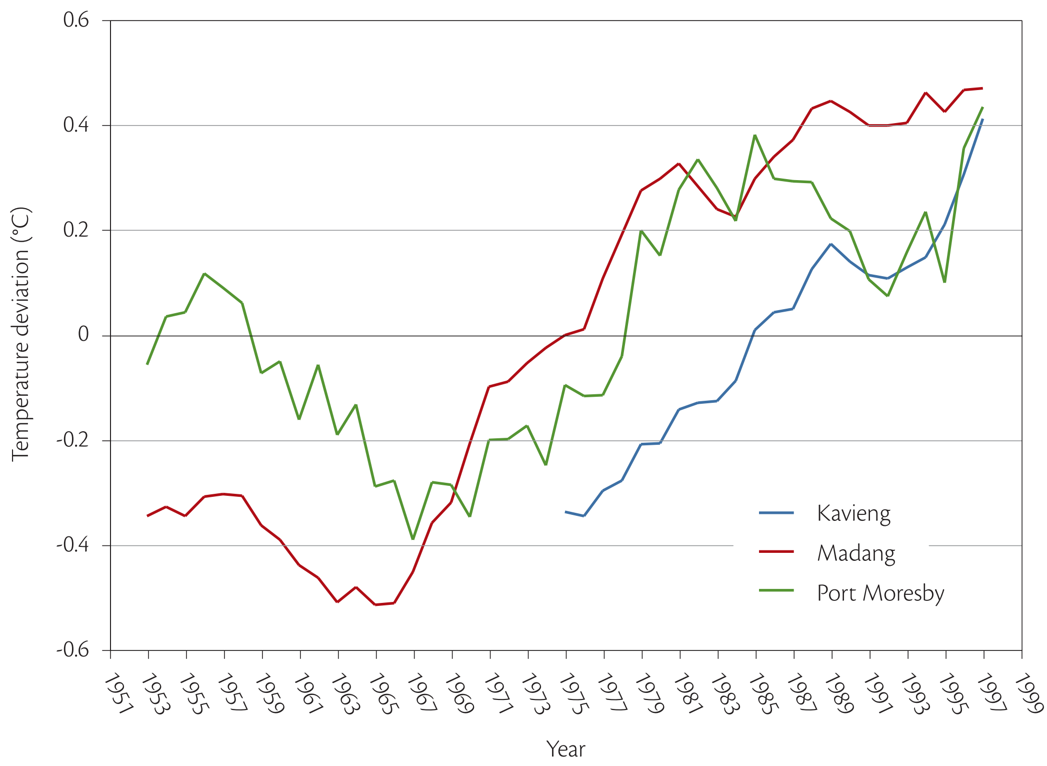


Figure 1.8.5 Temperature increases at Kavieng (1973–1999), Madang (1951–1999) and Port Moresby (1951–1999) (5-year running means). Source: Bourke et al. (2002).

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.

Sources

Bourke, R.M. (1989). Altitudinal limits of 230 economic crop species in Papua New Guinea. Unpublished paper. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Bourke, R.M., Humphreys, G.S. and Hart, M. (2002). Warming in Papua New Guinea: some implications for food productivity. Unpublished paper. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Bourke, R.M. and Betitis, T. (2003). Sustainability of agriculture in Bougainville Province, Papua New Guinea. Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Brown, J.S., Kenny, M.K., Whan, J.H. and Merriman, P.R. (1995). The effect of temperature on the development of epidemics of coffee leaf rust in Papua New Guinea. *Crop Protection* 14(8):671–676.

Cabanes, C., Cazenave, A. and Le Provost, C. (2001). Sea level rise during past 40 years determined from satellite and in situ observations. *Science* 294(5543):840–842.

Flannery, T. (2005). *The Weather Makers: The History and Future Impact of Climate Change*. The Text Publishing Company, Melbourne.

Haberle, S.G., Hope, G.S. and van der Kaars, S. (2001). Biomass burning in Indonesia and Papua New Guinea: natural and human induced fire events in the fossil record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 171(3–4):259–268.

Hulm, P. (1989). *A Climate of Crisis: Global Warming and the Island South Pacific*. Association of South Pacific Environmental Institutions, Port Moresby.

Inape, K. and Humphrey, B. (2001). Potential impact of global climatic change on smallholder farmers in PNG. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 73–78.

IPCC (Intergovernmental Panel on Climate Change) (2006). Working Group I Contribution to the Fourth Assessment Report of the IPCC. Climate Change 2007: The Physical Science Basis. Accessed 10 May 2006 at <http://www.climatescience.gov/Library/ipcc/wg14ar-review.htm>.

Kocher Schmid, C. (1991). *Of People and Plants: A Botanical Ethnography of Nokopo Village, Madang and Morobe Provinces, Papua New Guinea*. Basler Beiträge zur Ethnologie, Band 33. Ethnologisches Seminar der Universität und Museum für Völkerkunde, Basel.

Mueller, I., Namuigi, P., Kundi, J., Ivivi, R., Tandrapah, T., Bjorge, S. and Reeder, J.C. (2005). Epidemic malaria in the highlands of Papua New Guinea. *American Journal of Tropical Medicine and Hygiene* 72(5):554–560.

Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V.Y., Lorius, C., Pépin, L., Ritz, C., Saltzman, E. and Stievenard, M. (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399(6735):429–436.

Rosenberg, N.J. and Scott, M.J. (1994). Implications of policies to prevent climate change for future food security. *Global Environmental Change* 4(1):49–62.

Schneider, S.H. (1996). The future of climate: potential for interaction and surprises. In Downing, T.E. (ed). *Climate Change and World Food Security*. NATO ASI Series. Series I: Global Environmental Change, Volume 37. Springer, Berlin. pp. 77–113.

UNEP/GRID-Arendal (ed.) (2006). *Planet in Peril: An Atlas of Current Threats to People and the Environment*. UNEP/GRID-Arendal and Le Monde diplomatique, Norway and France.

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.

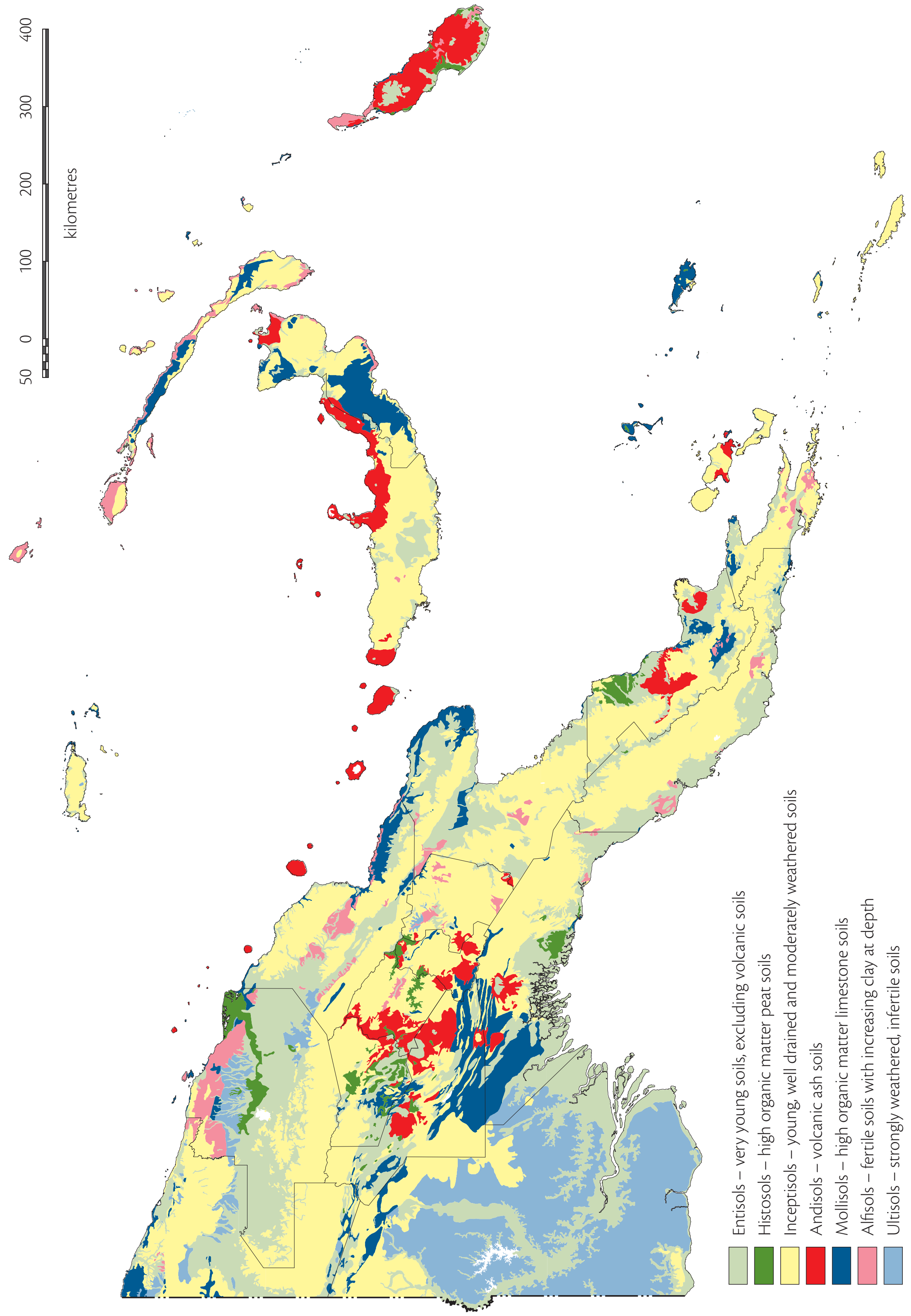


Figure 1.9.1 Distribution of USDA Soil Taxonomy soil orders. **Note:** The areas covered by Vertisols and Oxisols are too small to be shown on the map (see Table A1.9.1). Source: PNGRIS.

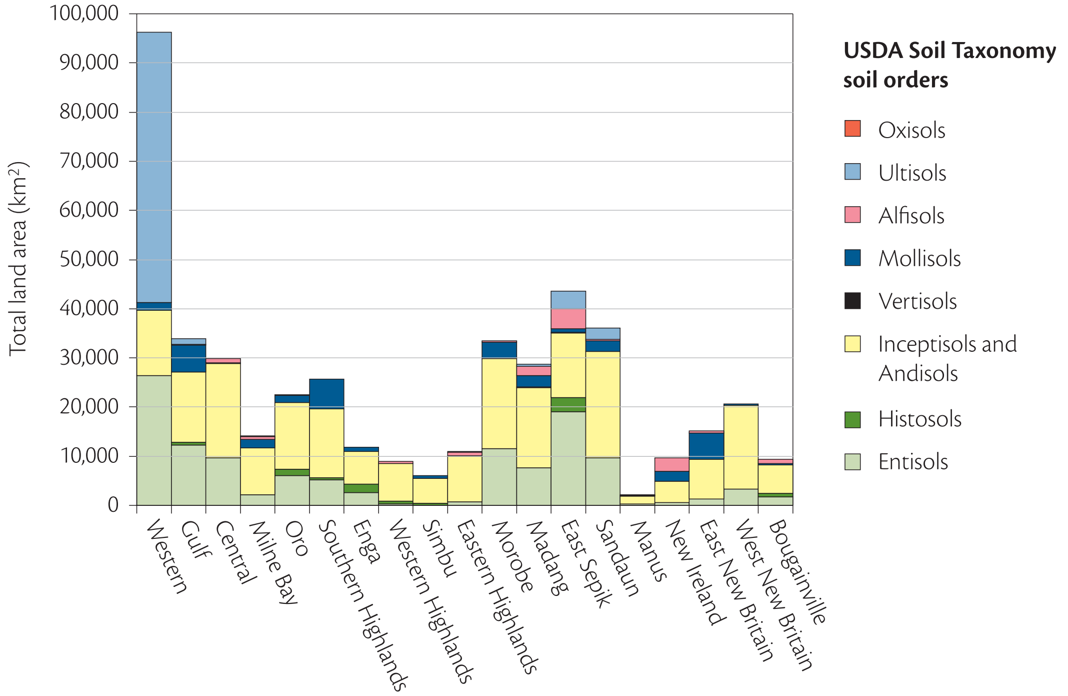


Figure 1.9.2 Distribution of USDA Soil Taxonomy soil orders by land area and province. Source: PNGRIS.

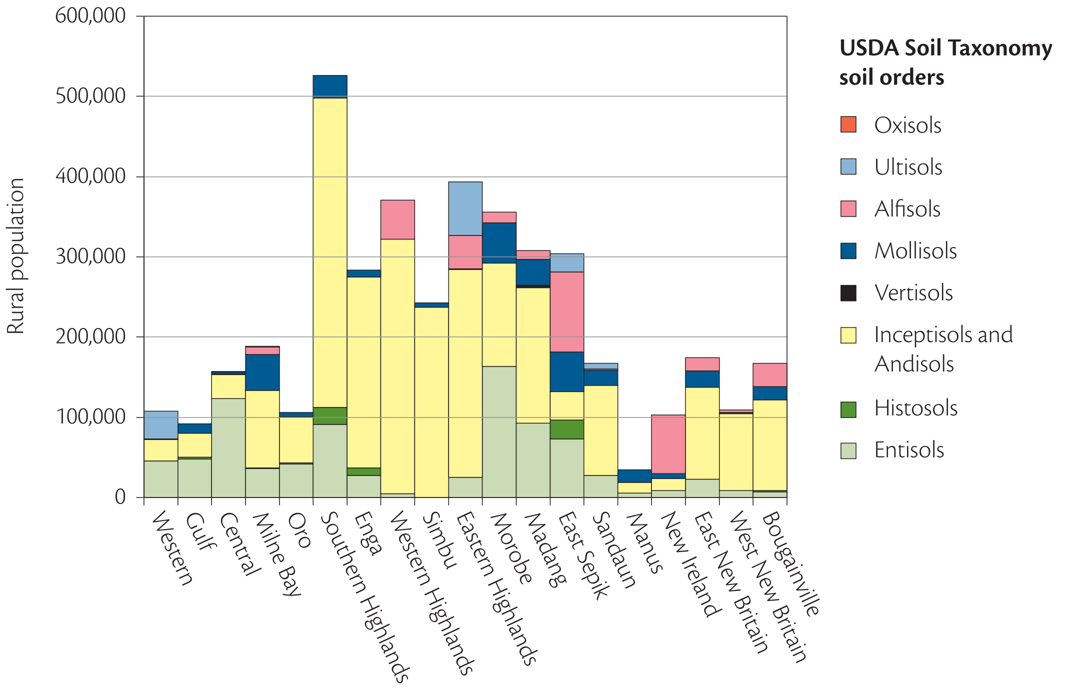


Figure 1.9.3 Distribution of USDA Soil Taxonomy soil orders by rural population and province. Sources: NSO (2002); PNGRIS.

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.

Sources

Bellamy, J.A. (1986). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Natural Resources Series No. 6. Division of Water and Land Resources, Commonwealth Scientific and Industrial Research Organisation, Canberra.

Bleeker, P. (1983). *Soils of Papua New Guinea*. Commonwealth Scientific and Industrial Research Organisation and Australian National University Press, Canberra.

Bourke, R.M. (1983). Crop micronutrient deficiencies in Papua New Guinea. Technical Report 83/3. Department of Primary Industry, Kainantu.

Dearden, P.N., Freyne, D.F. and Humphreys, G.S. (1986). Soil and land resource surveys in Papua New Guinea. *Soil Survey and Land Evaluation* 6(2):43–50.

Hartemink, A.E. and Bourke, R.M. (2001). Nutrient deficiencies in export tree and food crops: literature review and field observations. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 316–327.

Humphreys, G.S. (1991). Soil maps of Papua New Guinea: a review. *Science in New Guinea* 17(2):77–102.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

Wood, A.W. (1982). The soils of New Guinea. In Gressitt, J.L. (ed). *Biogeography and Ecology of New Guinea. Monographiae Biologicae*. Volume 42. Dr W. Junk Publishers, The Hague. pp. 73–83.

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%).

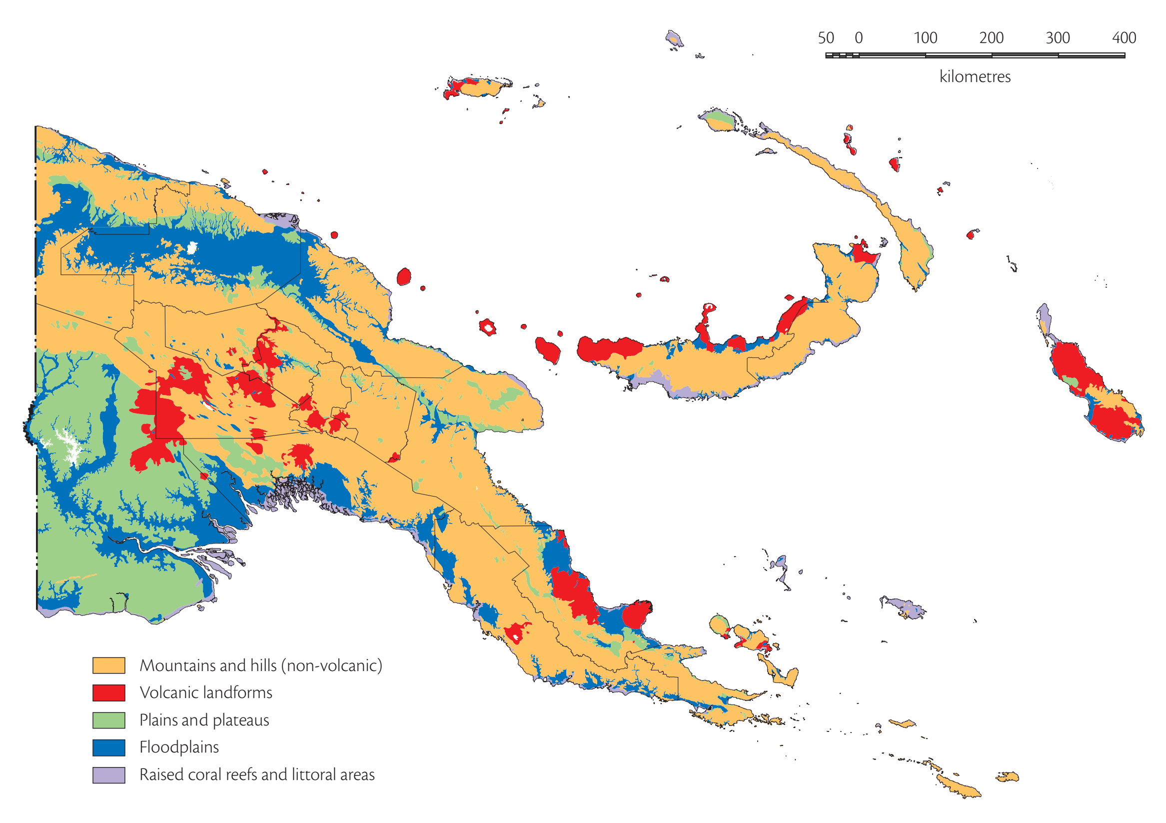


Figure 1.10.1 The five basic landforms of the PNG landscape. Sources: McAlpine and Quigley (c. 1995); PNGRIS.

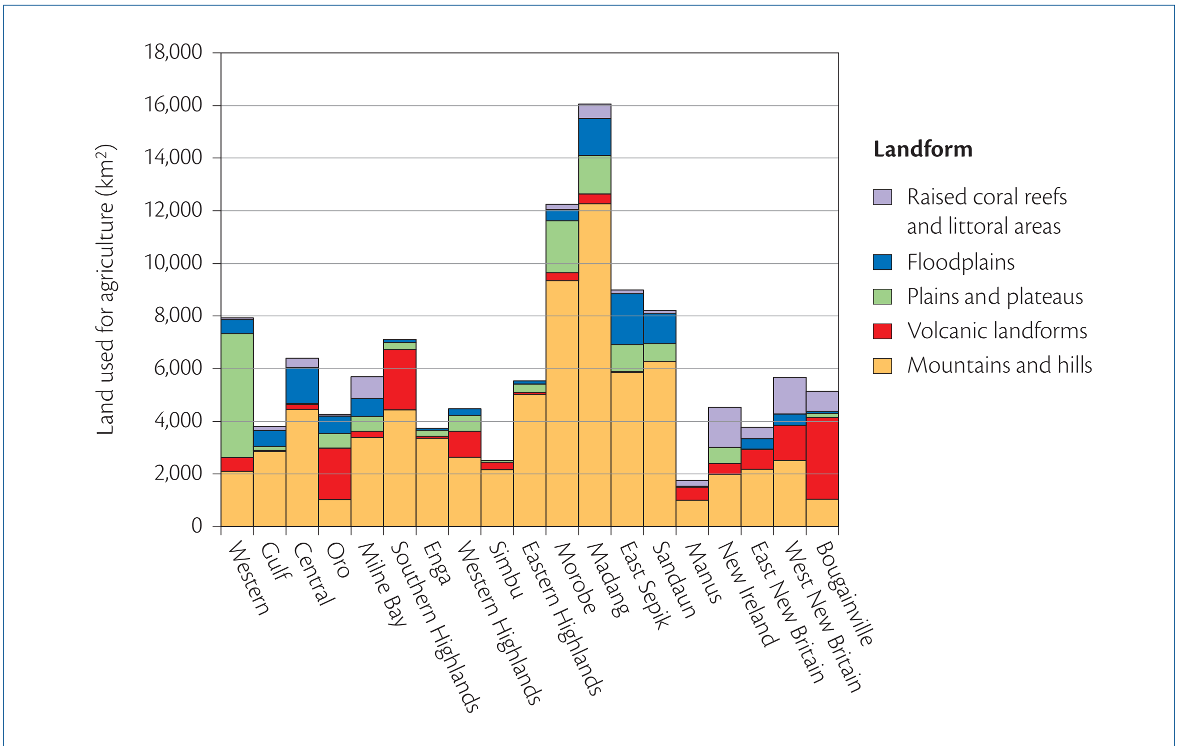


Figure 1.10.2 Land area used for agriculture by landform and province. Sources: McAlpine and Quigley (c. 1995); PNGRIS.

- 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%).

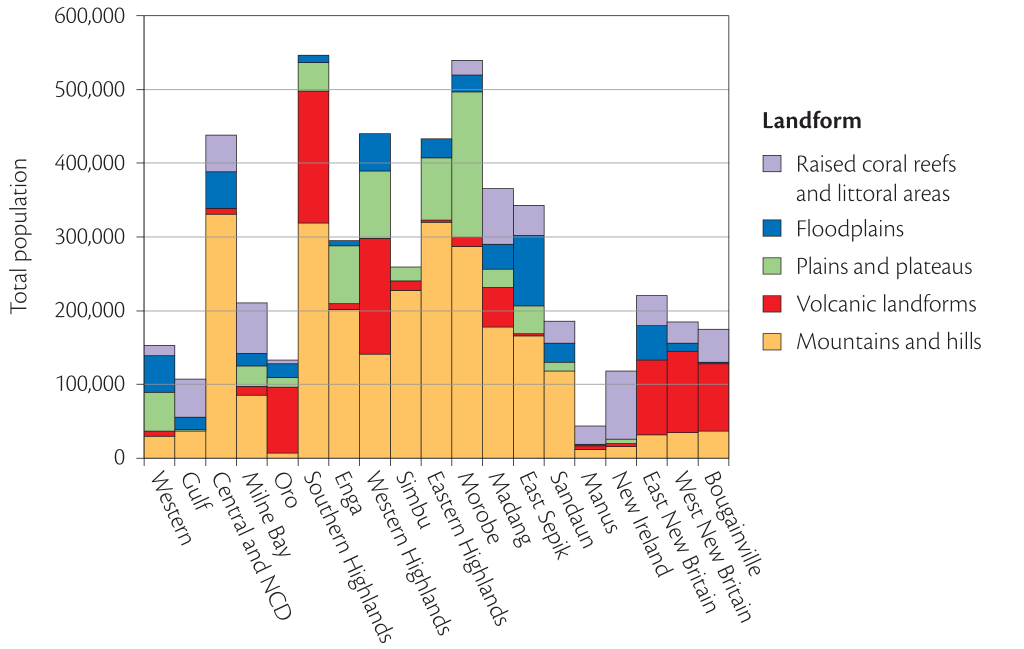


Figure 1.10.3 Total population (including urban and rural non-village populations) by landform and province.
Sources: McAlpine and Quigley (c. 1995); NSO (2002); PNGRIS.

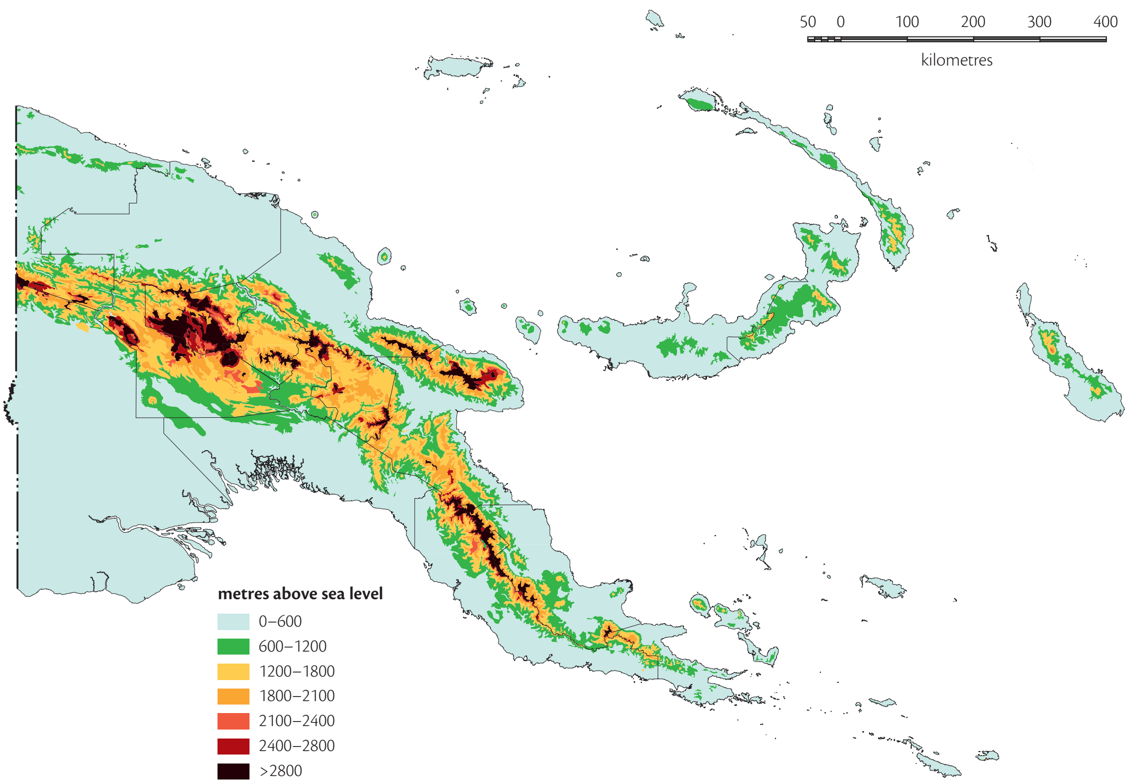


Figure 1.10.4 Altitude classes of the PNG landscape. Sources: McAlpine and Quigley (c. 1995); PNGRIS.

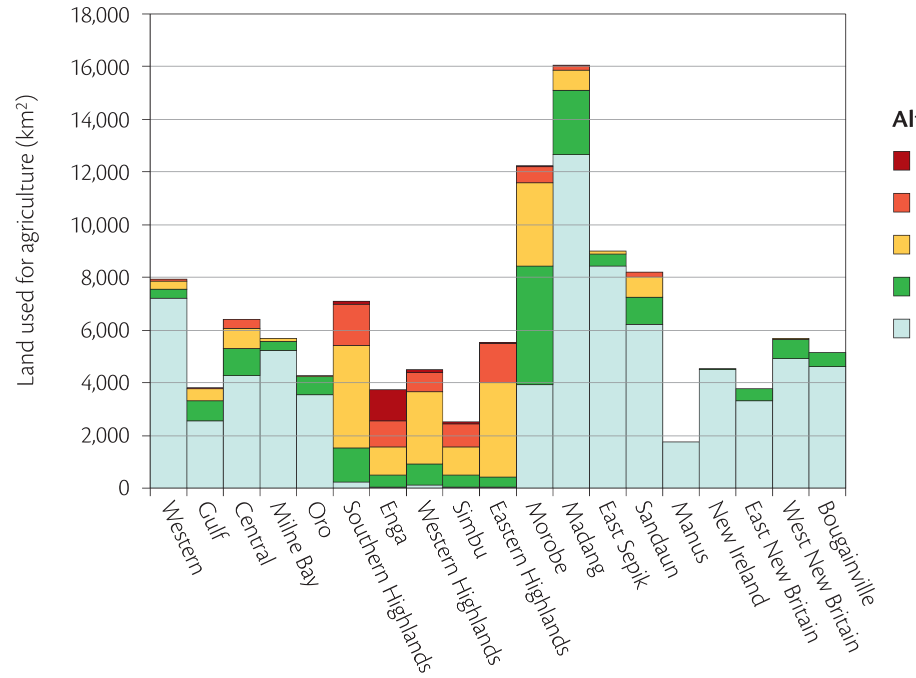


Figure 1.10.5 Land area used for agriculture by altitude class and province.
Sources: McAlpine and Quigley (c. 1995); PNGRIS.

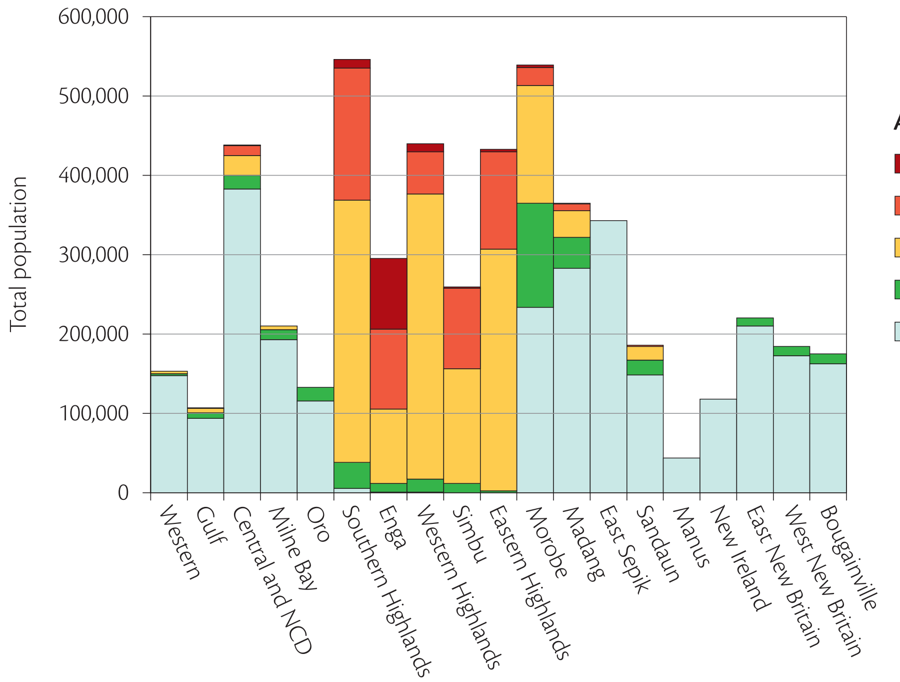


Figure 1.10.6 Total population (including urban and rural non-village populations) by altitude class and province.
Sources: McAlpine and Quigley (c. 1995); NSO (2002); PNGRIS.

- 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.

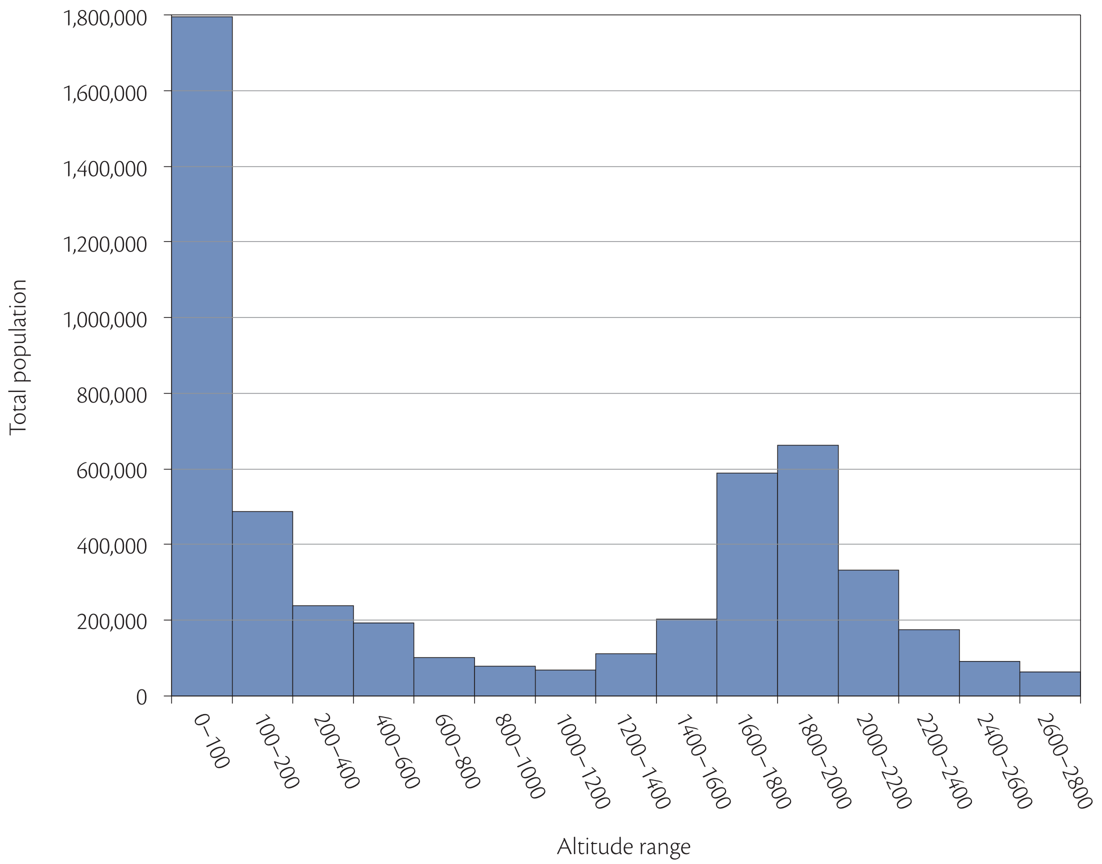


Figure 1.10.7 Total population (including urban and rural non-village populations) by altitude range.
Sources: NSO (2002); digital 1:250 000 topographic map; PNGRIS.

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/km^2)
	(km^2)	(%)	(km^2)	(%)				
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/km^2)
	(km^2)	(%)	(km^2)	(%)				
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.

Sources

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. 2nd edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

Löffler, E. (ed.) (1977). *Geomorphology of Papua New Guinea*. Commonwealth Scientific and Industrial Research Organisation and Australian National University Press, Canberra.

McAlpine, J. and Quigley, J. (c. 1995). *Natural Resources, Land Use and Population Distribution of Papua New Guinea: Summary Statistics from PNGRIS.* PNGRIS Report No. 7. Australian Agency for International Development, Canberra.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

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.

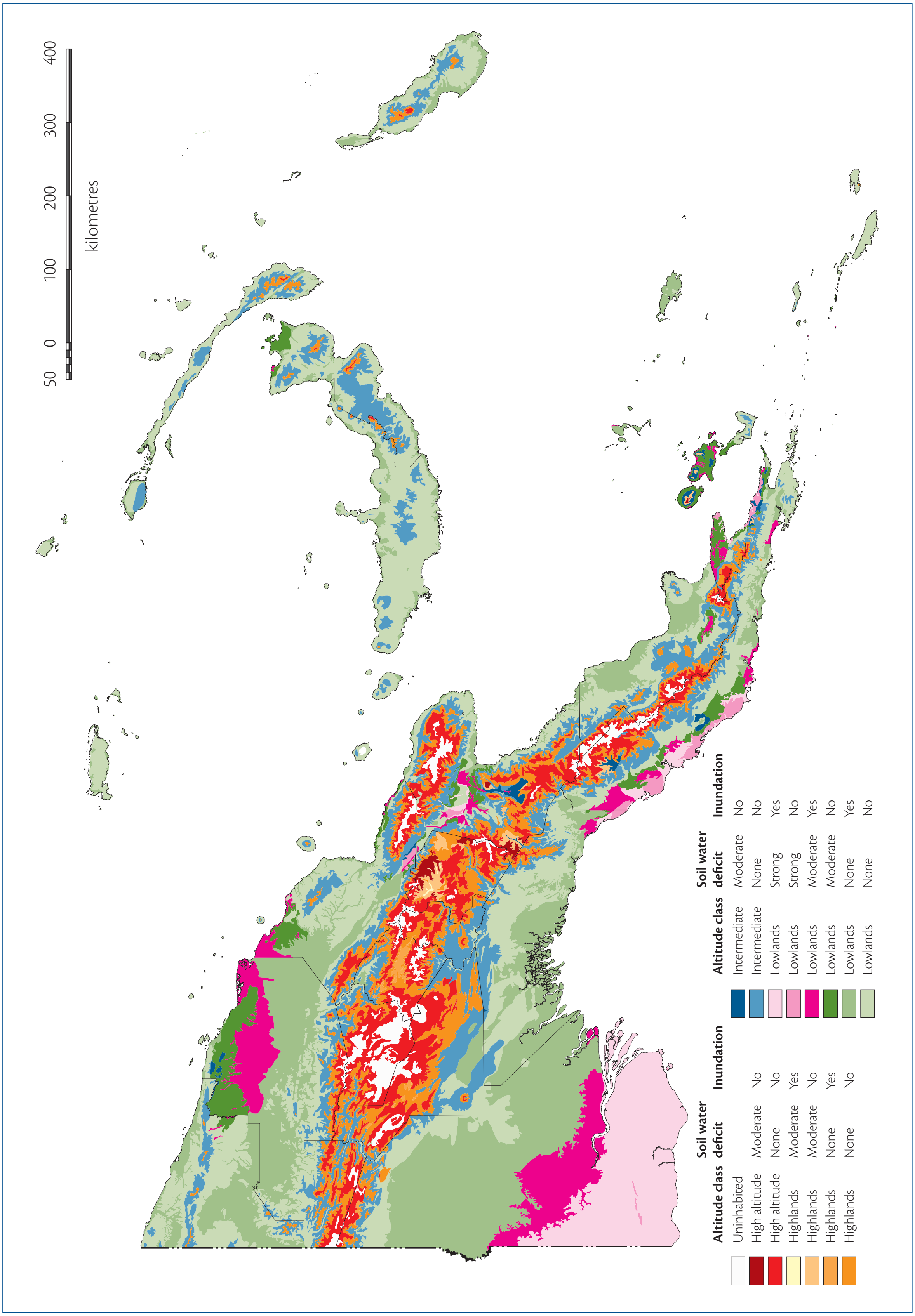


Figure 1.11.1 Agricultural environments based on altitude (temperature), soil water deficit (rainfall deficit) and inundation classes. Source: PNGRIS.

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.

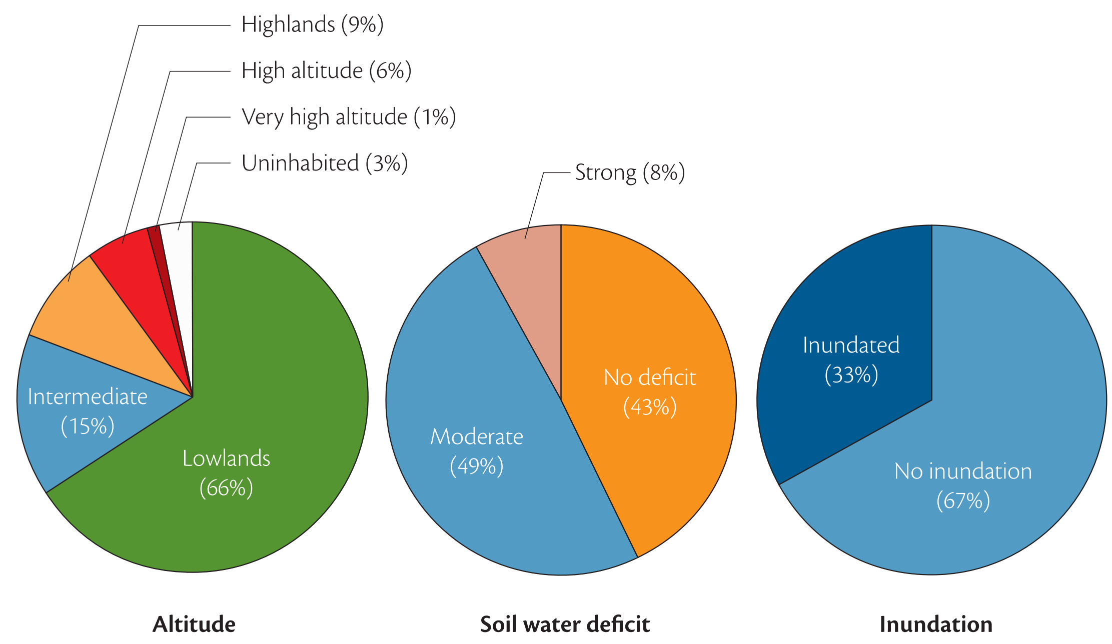


Figure 1.11.2 Proportion of the total land area by altitude (temperature), soil water deficit (rainfall deficit) and inundation classes. Source: PNGRIS.

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

Agricultural environment	Total land area (km^2)	Total land area (%)	Rural population	Proportion of rural population (%)	Proportion of population in altitude class (%)	Rural population density on total land area[a] (persons/km^2)
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.

Sources

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Second edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

Bourke, R.M. (1981). Agriculture in Papua New Guinea. *Alafua Agricultural Bulletin* 6(3):77–82.

Hanson, L., Allen, B.J. and Bourke, R.M. (2001). Mapping land resource vulnerability in the highlands of PNG. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 284–290.

Hanson, L.W., Allen, B.J., Bourke, R.M. and McCarthy, T.J. (2001). *Papua New Guinea Rural Development Handbook*. Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

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

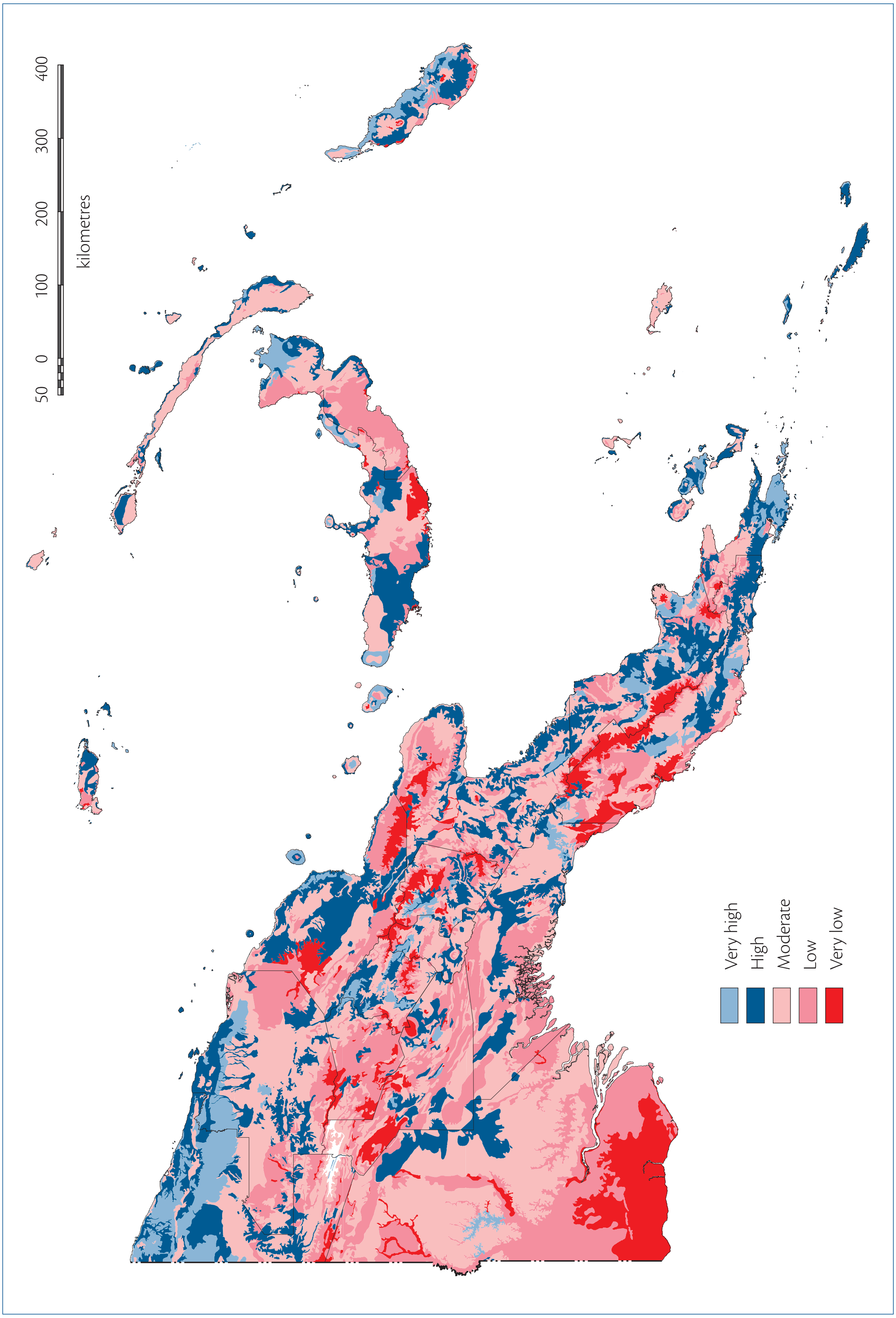


Figure 1.12.1 Land quality. Source: PNGRIS.

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.

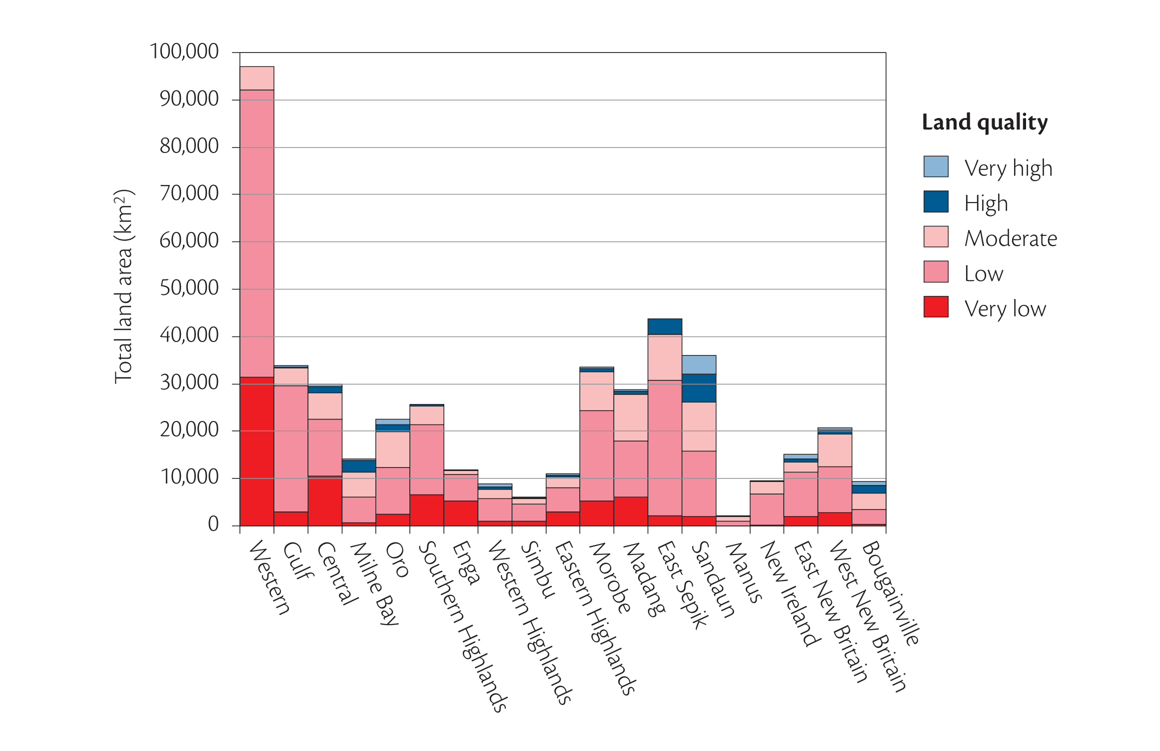


Figure 1.12.2 Total land area by land quality and province. Source: PNGRIS.

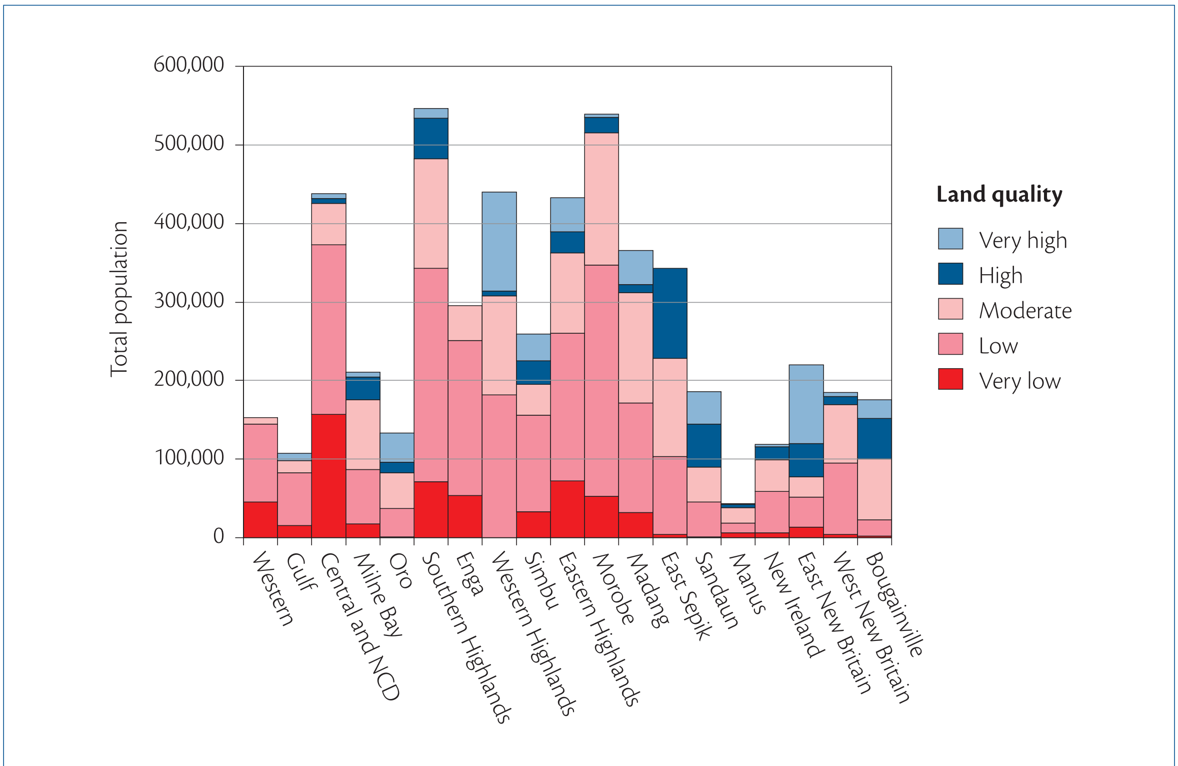


Figure 1.12.3 Total population (including urban and rural non-village populations) by land quality and province. Sources: NSO (2002); PNGRIS.

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).

Sources

Bourke, R.M. (2005). Sweet potato in Papua New Guinea: the plant and people. In Ballard, C., Brown, P., Bourke, R.M. and Harwood, T. (eds). *The Sweet Potato in Oceania: A Reappraisal. Ethnology Monographs 19 / Oceania Monograph 56*. Oceania Publications, University of Sydney and Ethnology, Department of Anthropology, University of Pittsburgh, Sydney and Pittsburgh. pp. 15–24.

Hanson, L.W., Bourke, R.M. and Yinil, D.S. (1998). *Cocoa and Coconut Growing Environments in Papua New Guinea. A Guide for Research and Extension Activities*. Australian Agency for International Development, Canberra.

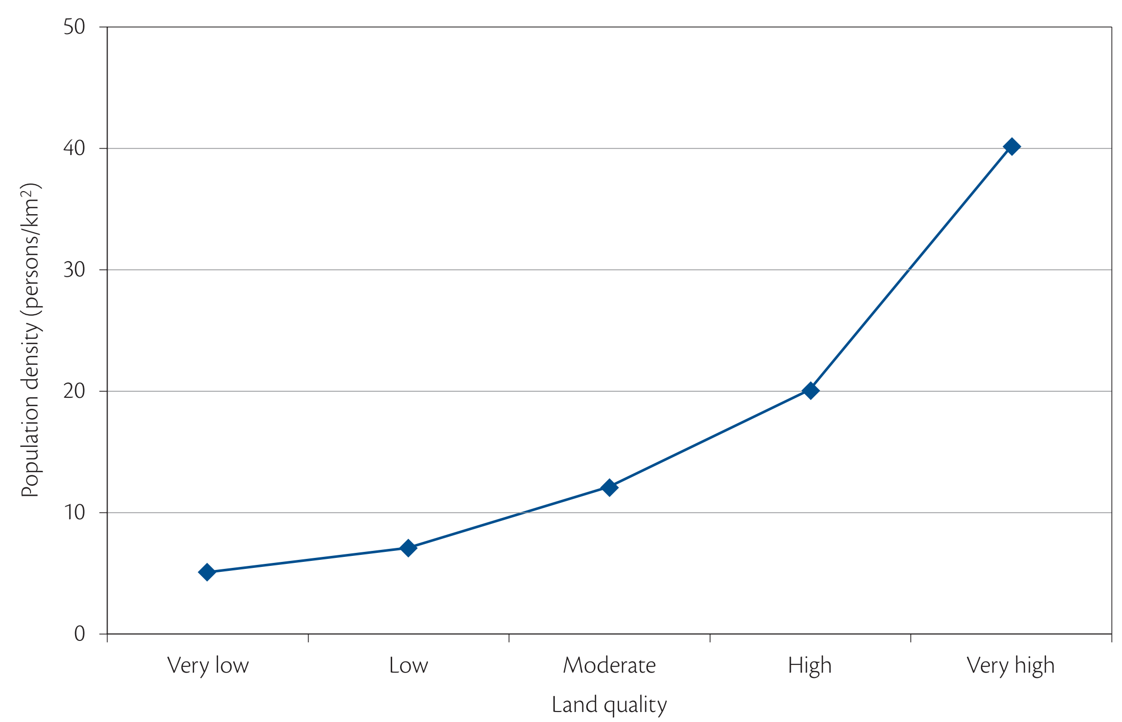


Figure 1.12.4 Association between land quality and population density. Sources: NSO (2002); PNGRIS.

Hanson, L., Allen, B.J. and Bourke, R.M. (2001). Mapping land resource vulnerability in the highlands of PNG. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 284–290.

Hanson, L.W., Bourke, R.M., Allen, B.J. and McCarthy, T.J. (2001). Mapping land resource potential and agricultural pressure in Papua New Guinea: an outline of new methods to assist rural planning. ACIAR Technical Reports No. 50. Australian Centre for International Agricultural Research, Canberra.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

Rossiter, D.G. (1990). ALES: a framework for land evaluation using a microcomputer. *Soil Use and Management* 6(1):7–20.

Trangmar, B.B., Giltrap, D.J., Burgham, S.J. and Savage, T.J. (1995). *Land Suitability Assessments for Selected Crops in Papua New Guinea*. PNGRIS Publication No. 8. Australian Agency for International Development, Canberra.

Venema, J.H. and Daink, F. (1992). Papua New Guinea Land Evaluation Systems (PNGLES). AG: TCP/PNG/ 0152 Field Document 1. Department of Agriculture and Livestock and Food and Agriculture Organization of the United Nations, Port Moresby and Rome.

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

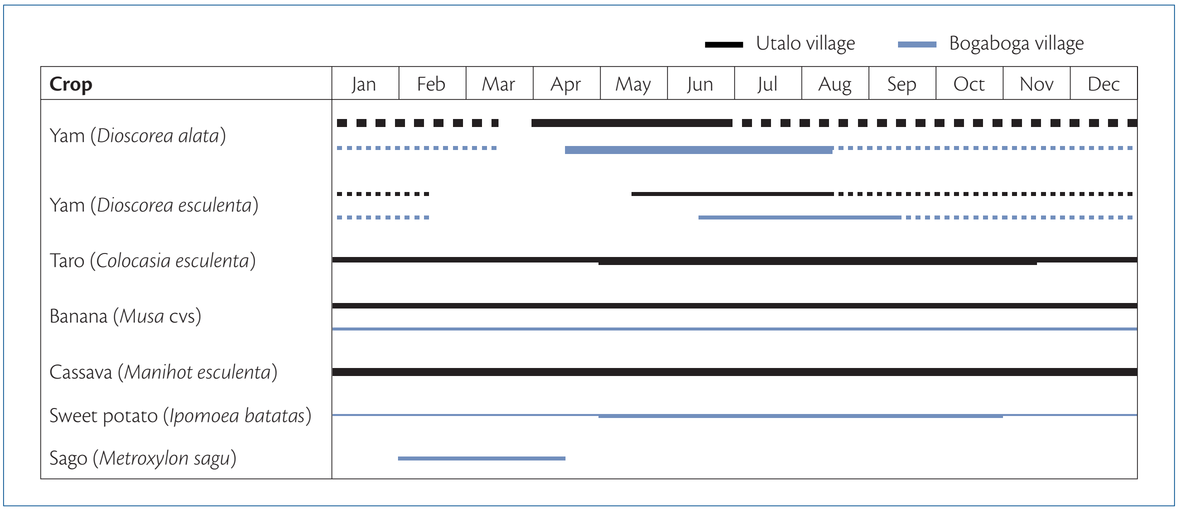


Figure 1.13.1 Food availability at Utalo village, Goodenough Island, and Bogaboga village, Cape Vogel area, Milne Bay Province. **Note:** A solid line indicates availability directly from food gardens. A dashed line indicates availability from storage. The thickness of the bands indicates relative abundance.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

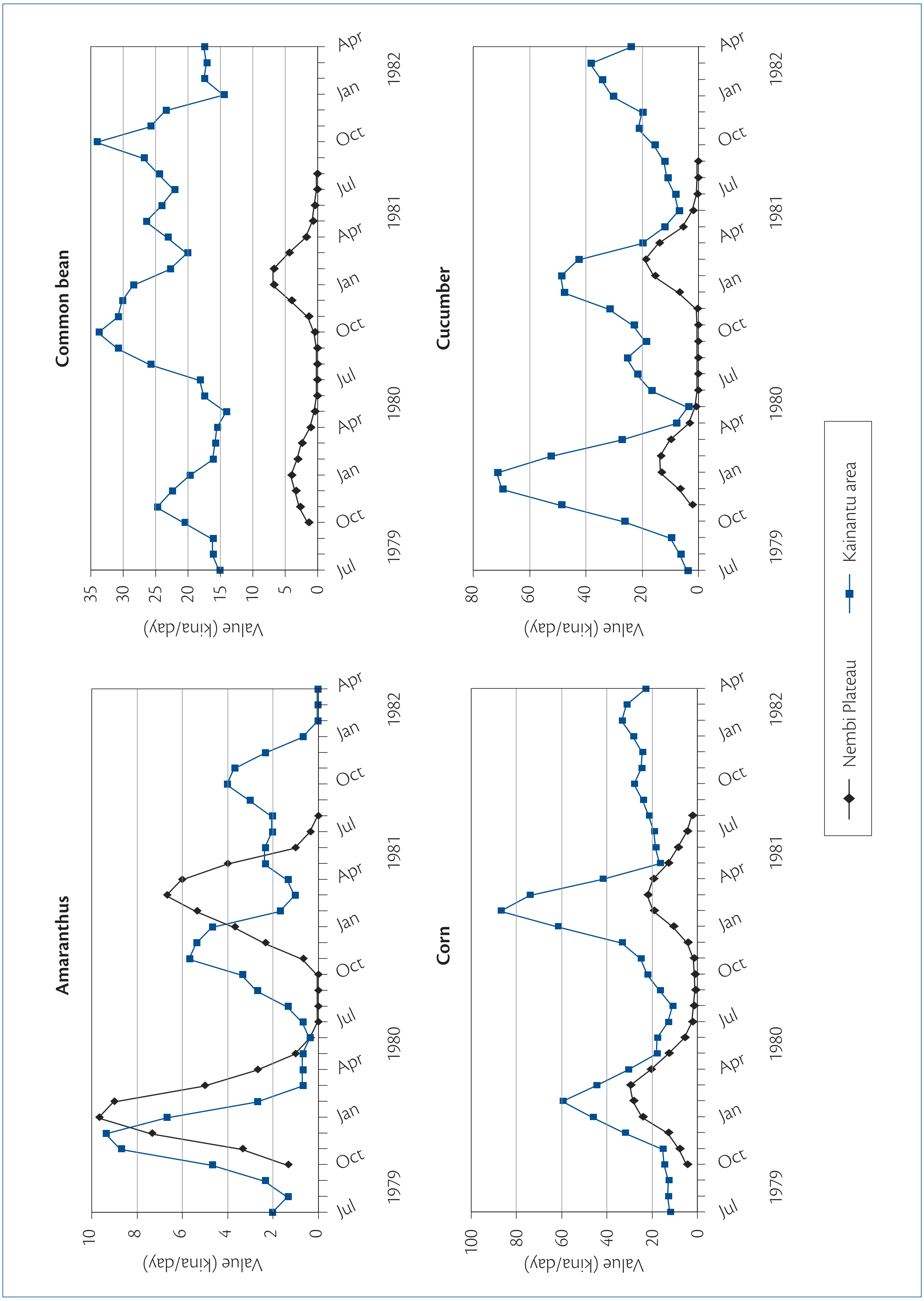


Figure 1.13.2 Availability of amaranthus (*Amaranthus* spp.), common bean (*Phaseolus vulgaris*), corn (*Zea mays*) and cucumber (*Cucumis sativus*) over a 3-year period in local food markets in the Kainantu area, Eastern Highlands Province, and Nembi Plateau, Southern Highlands Province. Data presented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

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).

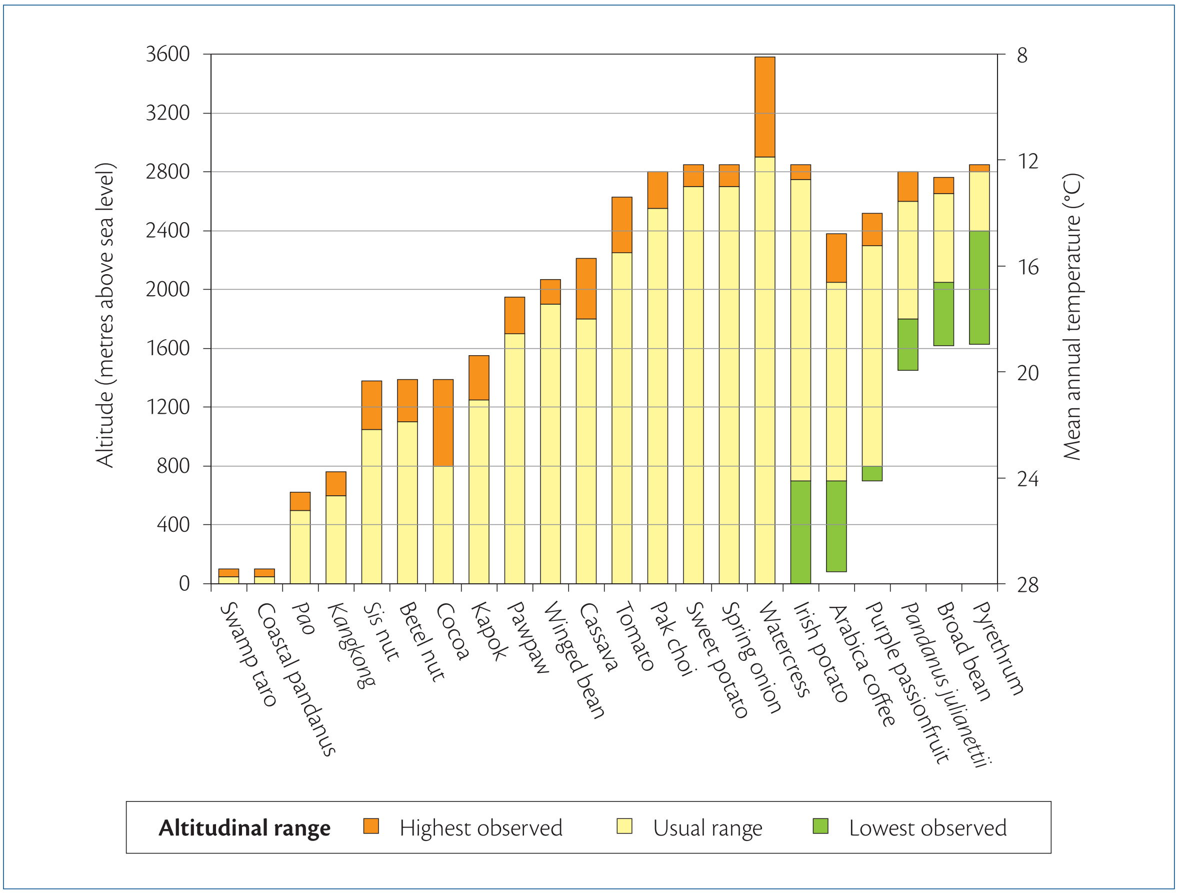


Figure 1.13.3 The usual and extreme altitudinal ranges of 22 crops in PNG. Source: Bourke (1989).

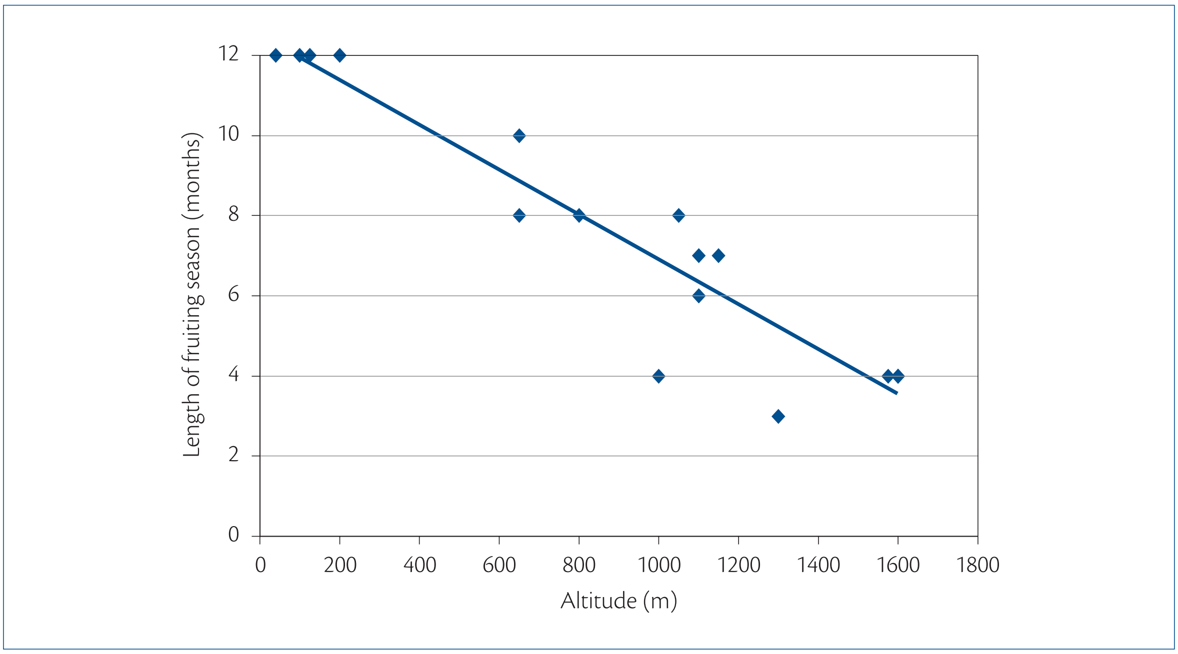


Figure 1.13.4 The length of the fruiting season of *marita* pandanus (*Pandanus conoideus*) versus altitude in PNG. Source: Bourke et al. (2004).

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.

Sources

Bourke, R.M. (1989). Altitudinal limits of 230 economic crop species in Papua New Guinea. Unpublished paper. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Bourke, R.M. (2005). Sweet potato in Papua New Guinea: the plant and people. In Ballard, C., Brown, P., Bourke, R.M. and Harwood, T. (eds). *The Sweet Potato in Oceania: A Reappraisal*. Ethnology Monographs 19 / Oceania Monograph 56. Oceania Publications, University of Sydney and Ethnology, Department of Anthropology, University of Pittsburgh, Sydney and Pittsburgh. pp. 15–24.

Bourke, R.M., Camarotto, C., D'Souza, E.J., Nema, K., Tarepe, T.N. and Woodhouse, S. (2004). *Production Patterns of 180 Economic Crops in Papua New Guinea*. Coombs Academic Publishing, Canberra.

Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds) (2001). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. (There are 17 papers in the section 'Food shortages and the 1997 drought and frosts', pp. 153–274, that include discussion of the impact of the drought and frosts on crop performance).

Hanson, L.W., Bourke, R.M. and Yinil, D.S. (1998). *Cocoa and Coconut Growing Environments in Papua New Guinea. A Guide for Research and Extension Activities*. Australian Agency for International Development, Canberra.

McAlpine, J.R., Keig, G. and Short, K. (1975). *Climatic tables for Papua New Guinea*. Division of Land Use Research Technical Paper No. 37. Commonwealth Scientific and Industrial Research Organisation, Melbourne.

Mogina, J. (2002). Changing knowledge of plants in transitional societies at Milne Bay, Papua New Guinea. PhD thesis. The Australian National University, Canberra.

Smith, J.M.B. (1977). Man's impact upon some New Guinea mountain ecosystems. In Bayliss-Smith, T.P. and Feacham, R.G. (eds). *Subsistence and Survival: Rural Ecology in the Pacific*. Academic Press, London. pp. 185–214.

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.

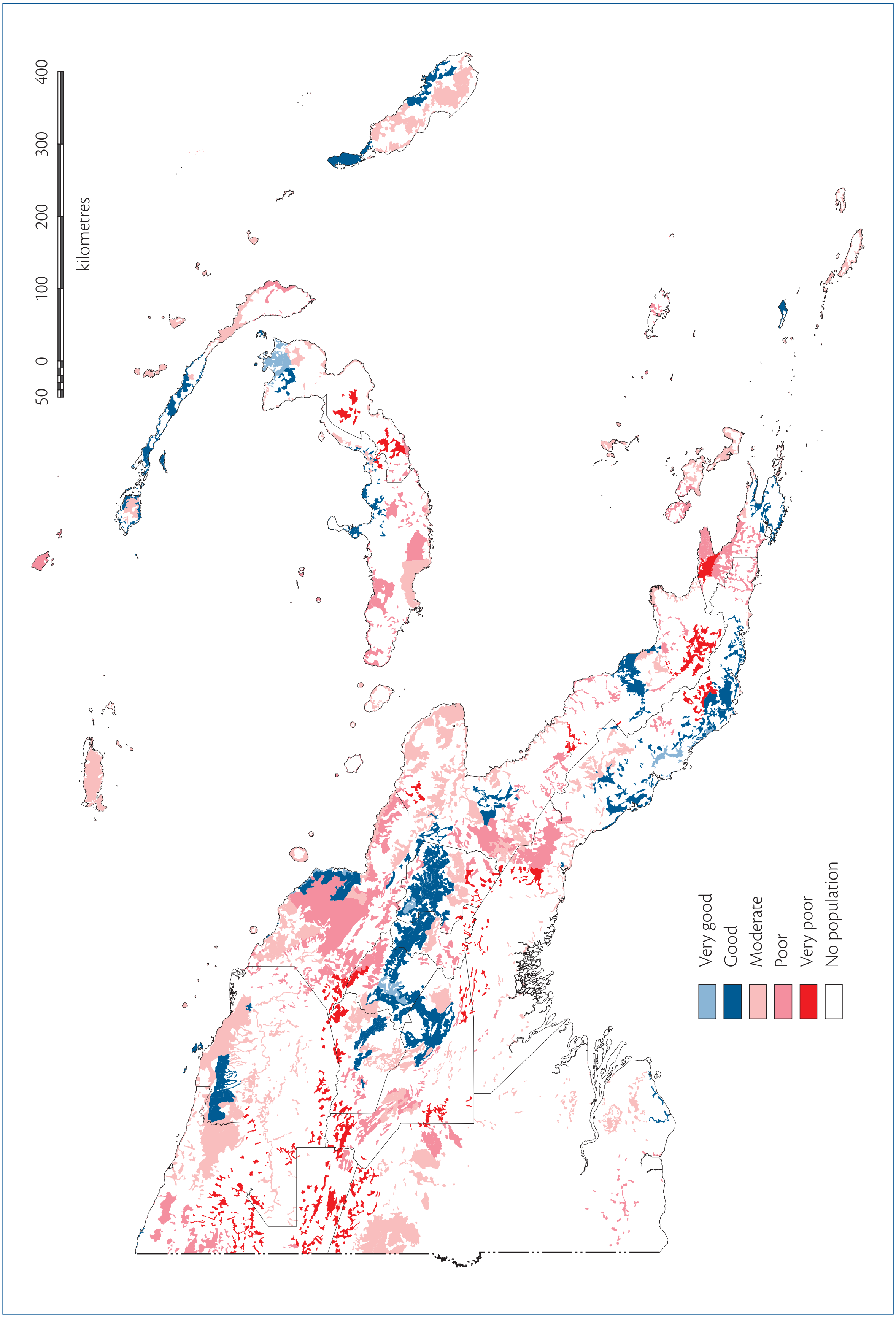


Figure 1.14.1 Access to markets and services. Source: MASP.

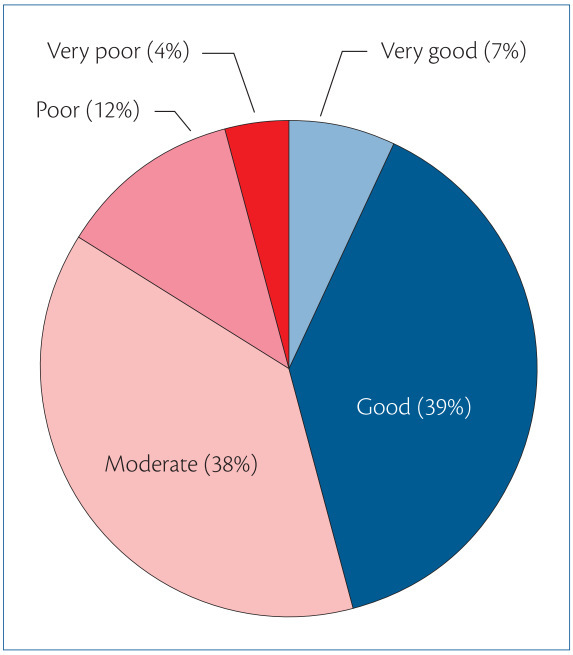


Figure 1.14.2 Access to markets and services by rural population. Sources: NSO (2002); MASP.

- 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.

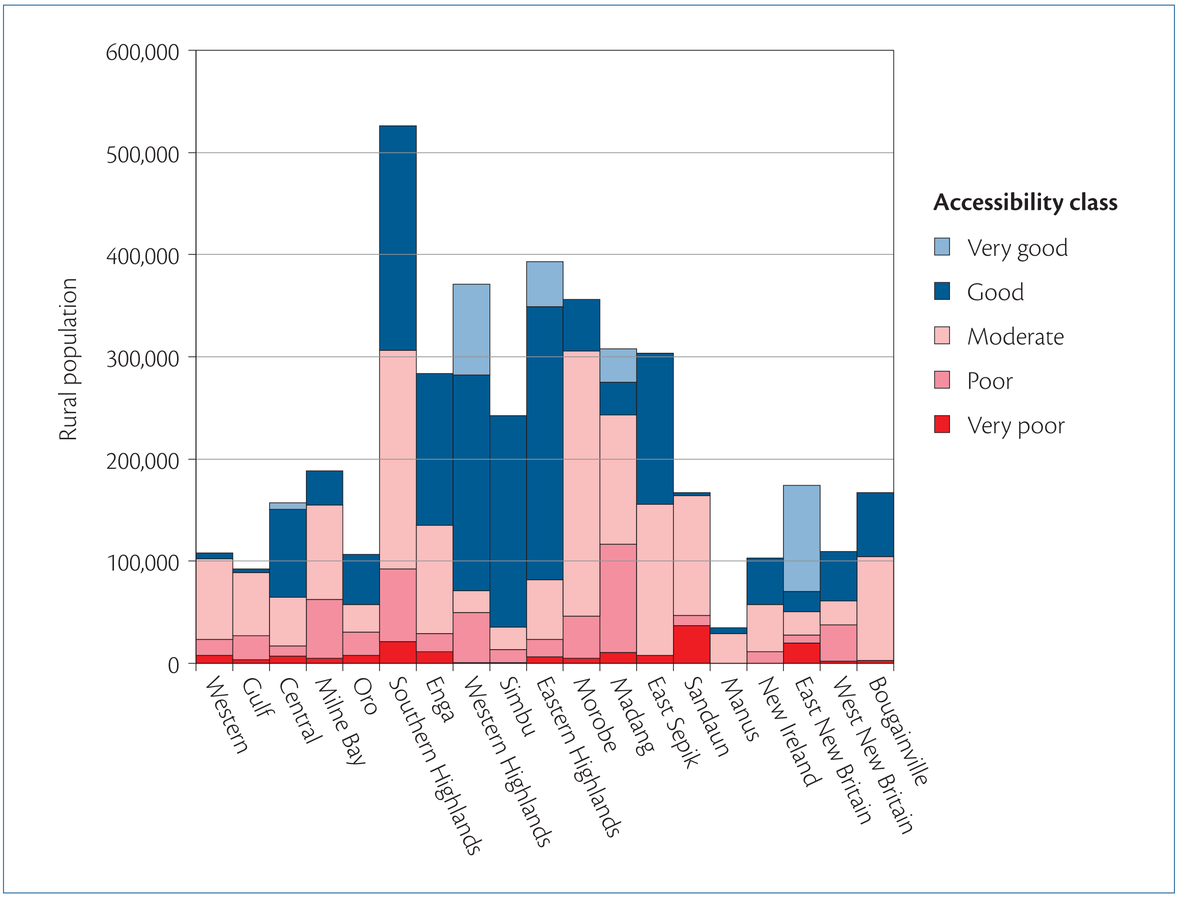


Figure 1.14.3 Rural population by accessibility class and province. Sources: NSO (2002); MASP.

Sources

Bourke, R.M., Allen, B.J., Hobsbawn, P. and Conway, J. (1998). *Papua New Guinea: Text Summaries*. Agricultural Systems of Papua New Guinea Working Paper No. 1. Two volumes. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

NSO (National Statistical Office of Papua New Guinea) (2002). Papua New Guinea 2000 Census: Final Figures. National Statistical Office of Papua New Guinea, Port Moresby.

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

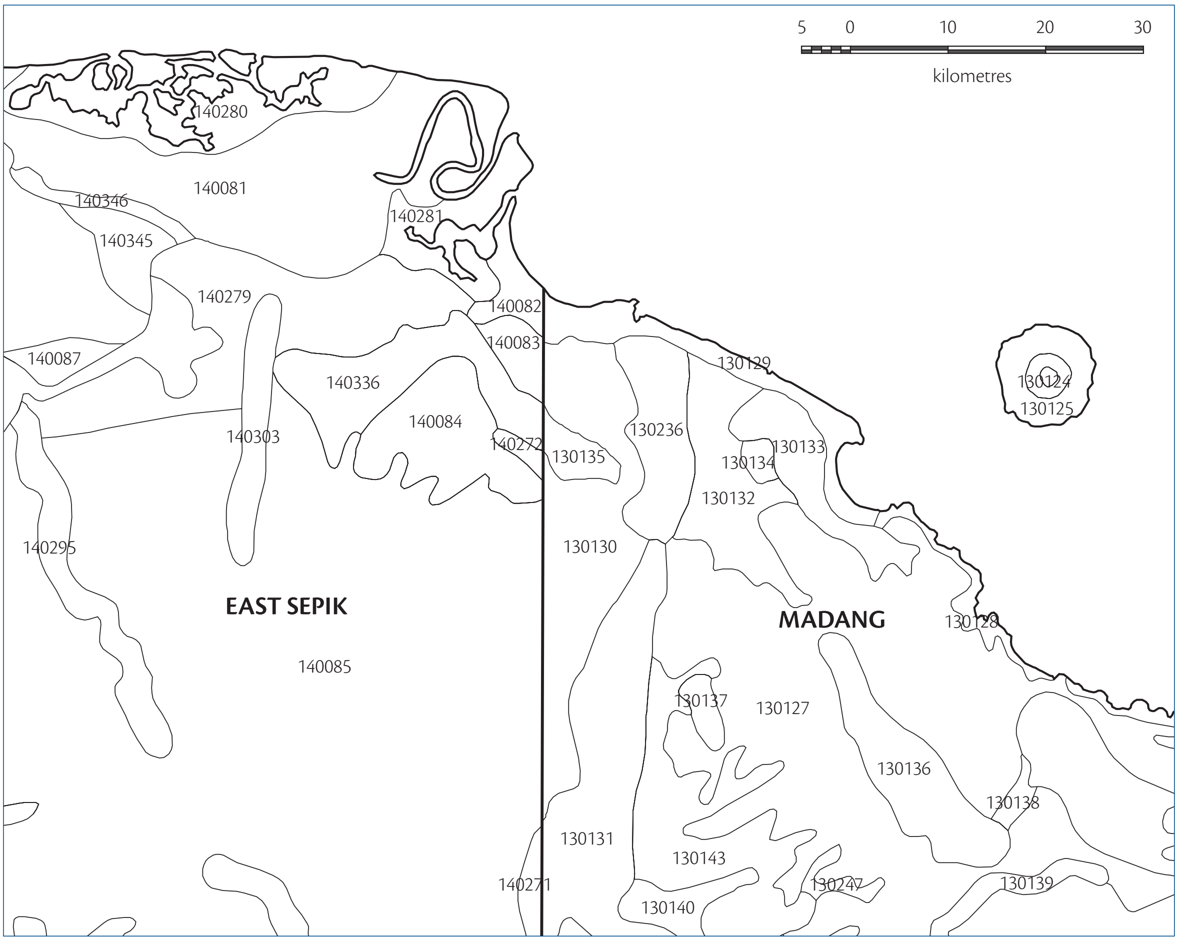


Figure 1.15.1 The PNGRIS GIS map showing resource mapping unit (RMU) numbers for part of East Sepik and Madang provinces. **Note:** To avoid cluttering the map, not all province RMU numbers are shown. Source: PNGRIS.

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.

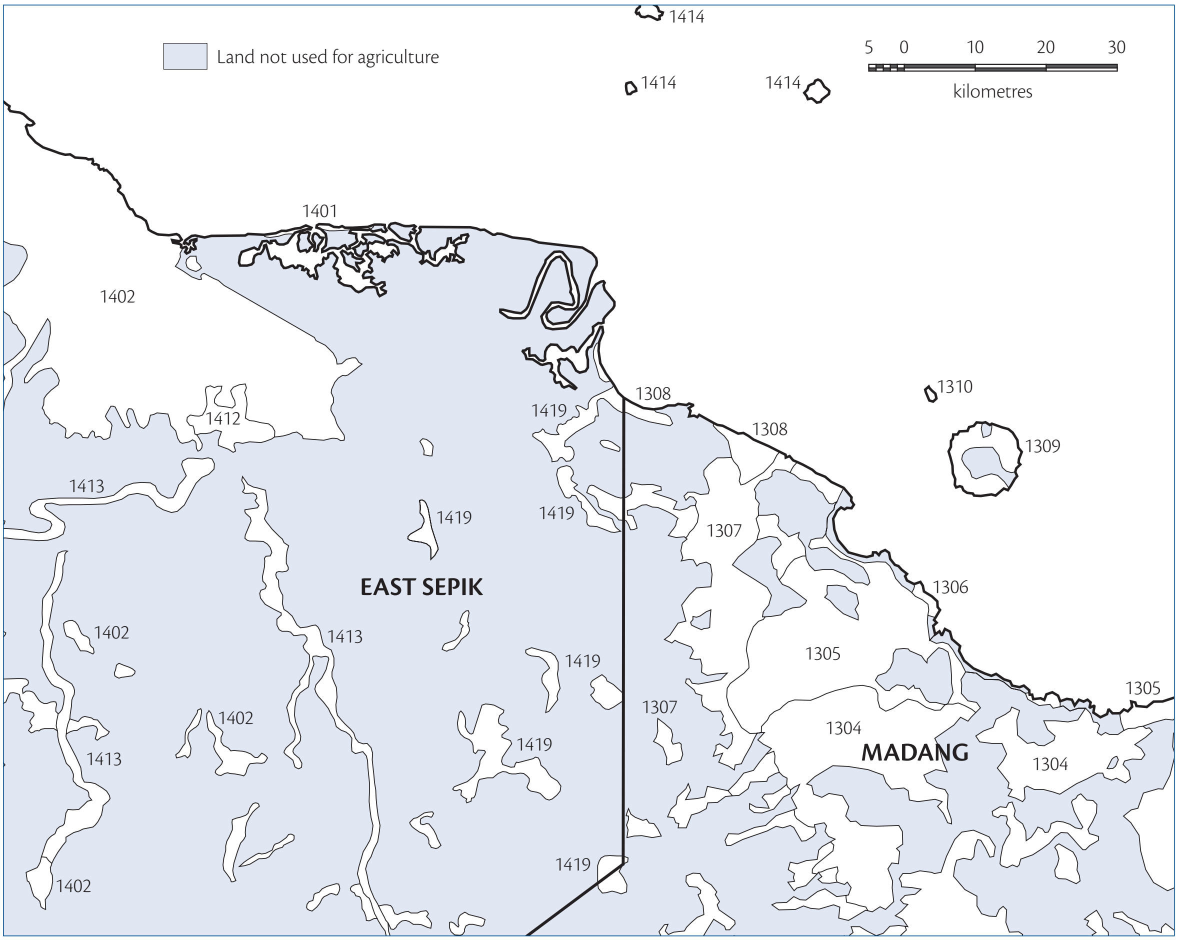


Figure 1.15.2 The MASP GIS map showing agricultural system (AGSYS) numbers for part of East Sepik and Madang provinces. **Note:** The shaded areas represent land that is not used for agriculture (see Section 1.2) and is excluded from MASP. Not all agricultural system numbers are shown. Source: MASP.

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.

Sources

Bellamy, J.A. (1986). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Natural Resources Series No. 6. Division of Water and Land Resources, Commonwealth Scientific and Industrial Research Organisation, Canberra.

Bellamy, J.A. and McAlpine, J.R. (1995). *Papua New Guinea Inventory of Natural Resources, Population Distribution and Land Use Handbook*. Second edition. PNGRIS Publication No. 6. Australian Agency for International Development, Canberra.

Bourke, R.M., Allen, B.J., Hobsbawn, P. and Conway, J. (1998). *Papua New Guinea: Text Summaries*. Agricultural Systems of Papua New Guinea Working Paper No. 1. Two volumes. Department of Human Geography, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

McAlpine, J.R., Keig, G., Bellamy, J.A., Bleeker, P., Cuddy, S.M., Hackett, C., Hide, R.L., Saunders, J.C. and Freyne, D.P. (1986). A natural resources information system for village agriculture in PNG. *CSIRO Division of Water and Land Resources Research Report 1983–85*. Commonwealth Scientific and Industrial Research Organisation, Canberra. pp. 78–86.

McAlpine, J. and Quigley, J. (c. 1995). *Natural Resources, Land Use and Population Distribution of Papua New Guinea: Summary Statistics from PNGRIS*. PNGRIS Report No. 7. Australian Agency for International Development, Canberra.

Trangmar, B.B., Basher, L.R. and Rijkse, W.C. (1995). *Land Resource Survey, Upper Ramu Catchment Papua New Guinea: Database Attributes*. PNGRIS Report No. 3. Australian International Development Assistance Bureau, Canberra.

Vovola, P. and Allen, B.J. (2001). Computer managed databases relevant to agriculture in PNG. In Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds). *Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference*. ACIAR Proceedings No. 99. Australian Centre for International Agricultural Research, Canberra. pp. 467–475.