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Land use change and population growth in the Morobe Province of Papua New Guinea between 1975 and 2000

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Abstract

The relation between human population growth and land use change is much debated. Here we present a case study from Papua New Guinea where the population has increased from 2.3 million in 1975 to 5.2 million in 2000. Since 85% of the population relies on subsistence agriculture, population growth affects agricultural land use. We assessed land use change in the Morobe province (33,933 km^2) using topographic maps of 1975 and Landsat TM images of 1990 and 2000. Between 1975 and 2000, agricultural land use increased by 58% and population grew by 99%. Most new agricultural land was taken from primary forest and the forest area decreased from 9.8 ha $person^{-1}$ in 1975 to 4.4 ha $person^{-1}$ in 2000. Total population change and total land use change were strongly correlated. Most of the agricultural land use change occurred on Inceptisols in areas with high rainfall (>2500 mm $year^{-1}$) on moderate to very steep slopes (10–56%). Agricultural land use changes in logged-over areas were in the vicinity of populated places (villages), and in close proximity to road access. There was considerable variation between the districts but districts with higher population growth also had larger increases in agricultural areas. It is concluded that in the absence of improved farming systems the current trend of increased agriculture with rapid population growth is likely to continue.

Keywords: Land use change; Population growth; Agricultural expansion; Agro-ecological conditions; Papua New Guinea

1. Introduction

Global land use has significantly changed in the past decades. Historically, the driving force for most land use changes is population growth (Ramankutty et al., 2002) although there are several interacting factors involved (Lambin et al., 2001, 2003). At the global and supra-national scales, population growth is often used as a proxy for land use change (Kok, 2004) but at lower scales a set of complex drivers are important (Lambin et al., 2001). Land use change is mainly caused by human activities.

Objectives for land use change differ between the developed and developing countries. In developed countries, land use change is based on economic reasons such as large-scale farming or urban development and an increasing need to conserve biodiversity and environmental quality for current and future generations (Bouma et al., 1998), whereas in the developing countries, rapid population growth, poverty and the economic situation are the main driving forces (Lambin et al., 2003; Meertens et al., 1996; Ramankutty and Foley, 1999).

The need for increased food production results, amongst others, in the conversion of forest and grassland to cropland. A region or country's ability to supply food is determined by productive cropland, the ability to maintain crop yields, or the ability to purchase imported food. Globally, cropland decreased from 0.75 ha $person^{-1}$ in 1900 to 0.35 ha $person^{-1}$ in 1990 (Ramankutty et al., 2002) and most of the production increases in the past decades have resulted from higher crop yields (Greenland, 1997). There are, however, large differences between different countries and regions—both in the extent that land use has changed and human population and crop yields have increased.

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Some areas in the world appear to be more affected by rapid land-cover change because they are studied more intensively (Lambin et al., 2003).

Papua New Guinea is a developing country where population has grown exponentially in the past decades. About 85% of the population lives in rural areas and depends on subsistence agriculture for their livelihoods. Forests cover more than 70% of the land area and 97% of the land is privately owned (Pat, 2003; Saunders, 1993). The average population density in the highlands region is 22 persons km^{-2}; whereas the national population density is 11 persons km^{-2}. A national study showed little relationship between population growth and agricultural land use change (McAlpine et al., 2001). Environmental and socio-economic conditions differ markedly between provinces and to obtain insight into land use changes at a lower scale, we selected the Morobe province to investigate changes in population in relation to land use change.

2. Study area, data and methods

2.1. Study area

The Morobe Province has nine districts and covers an area of 33,933 km^2, accounting for 7% of the total land area in Papua New Guinea (Fig. 1). The population was approximately 539,000 in 2000. A major part of the province is covered by primary forest. The topography ranges from sea level to over 4000 m a.s.l. and plate tectonics are active. The vast Markham Valley is dominated by grassland that spans from Lae city westward through Huon to Kaiapit district dividing the Saruwaged, and Finisterre mountains to the north and the Highlands mountain systems to the south. These mountains and hills comprise 77% of the total land area. In the lowlands, the climate is hot and humid with an average temperature of 30° and a mean annual rainfall of about 2900 mm $year^{-1}$. Wau, Lae, Siassi, parts of Menyamya, Huon and Finschhafen districts are some of the wettest areas with up to 5000 mm rain $year^{-1}$. Dominant soils are Humitropepts, Dystropepts, Troporthents and Rendolls (Bleeker, 1983). The provincial capital, Lae city, has 15% of the total population in the province.

2.2. Topographic maps and Landsat images

Topographic maps from 1975 and Landsat thematic mapper images of 1990 and 2000 were used to investigate changes in land use. One topographic map sheet covers an area of 55 × 55 km and 25 sheets covered the whole province. The map scale is 1:100,000 and spatially referenced to transverse mercator projection on Australian geodetic datum of 1966 (AGD66). The geometric accuracy is up to 40 m horizontally and 17 m vertically with contour intervals at 40 m. The topographic map sheets were scanned at 300 dpi scan resolution and georeferenced to AGD66, which results in a spatial resolution of 8.5 m.

The Landsat images fully covered the study area for both 1990 and 2000. Their overall spatial resolution was 28.5 m, however; the resolution for band 8 of ETM+ for 2000 was 14.25 m, which sharpens the other bands. Both images were

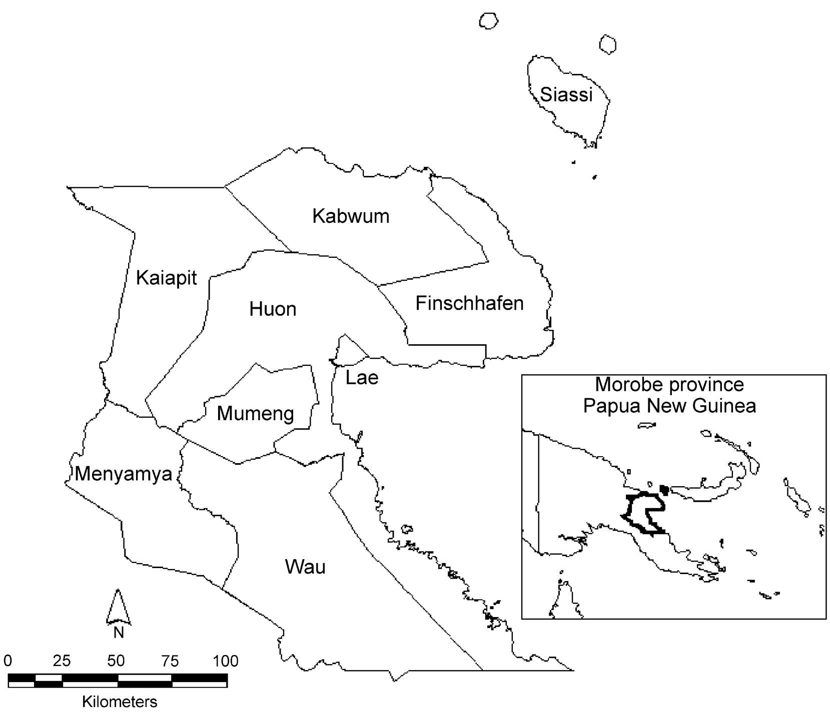

Fig. 1. Districts in the Morobe province of Papua New Guinea.

geometrically corrected and orthorectified by NASA to form seamless mosaics or tiles of 6° longitude and 5° latitude. The tiles were spatially referenced to universal transverse mercator projection of 1984 (UTM84). The spectral bands in both images were reduced to 2 (green), 4 (near infrared) and 7 (short wave infrared). Band 2 is useful for human-induced and vegetation differentiation; band 4 is useful for vegetation types determination and band 7 is sensitive to rock types. The images were reprojected to AGD66 and clipped to fit the study area. Both images contained less than 10% cloud cover along the higher altitude and mountainous areas which are mostly under forest. The areas under cloud cover were updated using a combination of Papua New Guinea resource information system (PNGRIS), forest information system (FIMS) and agriculture systems (AGSYS) datasets (see Section 2.3) to derive land use.

2.3. Auxiliary data

In addition to the topographic maps and Landsat images, we used various data sets to improve the assessment of land use change. Auxiliary data sets for this study were the PNGRIS, AGSYS, FIMS and population data. PNGRIS is a polygon-based natural resource data set with spatial units called resource mapping units (RMUs) in MapInfo and ESRI shape formats. RMUs are based on common set of geographic attributes which include land-form, geology, climate and administrative boundaries (Bellamy and McAlpine, 1995). The RMU boundaries are derived from 1:500,000 base maps called tactical pilotage charts (TPC) which contain appropriate topographical information for mapping the distribution of natural resources. The department of agriculture and livestock (DAL) is the custodian of the PNGRIS database and other government departments and agencies acquire license to use. Census data points are overlaid with RMU polygons and through GIS spatial operations the RMU attribute table is updated with census data. The population in the RMU is assumed to be equally distributed.

AGSYS is a polygon-based agricultural systems data set of Papua New Guinea which is also under the custody of DAL. The mapping units are based on agricultural system on a common set of attributes such as crop types, cultivation intensity, cropping period, fallow type, fallow period, cash crop activity, soil fertility maintenance technique and other aspects related to agriculture (Bourke et al., 1998, 2002). AGSYS data were used for checking digitized land use and identifying land use that was under cloud cover on the satellite images.

FIMS is a polygon-based forest data set compiled from 1:100,000 topographic maps and contains forest data such as major forest species and forest zones of Papua New Guinea in Mapinfo format. FIMS contains land use as a land cover type and this was used to check land use and also for areas under cloud cover.

2.4. Assessing land use change

The land use classification for this study was based on the topographic maps of 1975 as follows: (i) agriculture, (ii) forest, (iii) grassland, (iv) plantation, (v) urban and (vi) water. The 1975 topographic maps were derived from aerial photographs at scale 1:100,000 through photogrammetry. These topographic maps show the six land use types for 1975. Land use for 1975 has been assessed by screen digitizing the scanned topographic images as background maps, similar to Li et al. (2004). This was preferred above adopting the existing 1975 land use map as a base map (McAlpine and Freyne, 2001). A copy of the digitized 1975 land use was used to update 1990 land use by using the 1990 Landsat image as background. Land use changes were assessed visually and edited to 1990 land use in ArcGIS. The procedure was repeated to assess land use changes for 2000 by making a copy of 1990 land use and the 2000 Landsat image as background.

The 3 band Landsat images when displayed in default true colour showed shades of green for vegetation, and lavender, magenta or pale pink for urban areas and bare soils. Water is shown black to dark blue and cloud cover shows white while cloud shadows as black. From the image, water, urban, grassland and forest could easily be distinguished and also plantation and agriculture covering larger areas (>0.5 ha) are easily identified, but areas smaller than 0.5 ha were difficult. To update land use boundaries for 1990 and 2000, image enhancements were used to recognize roads, built-up areas and plantations. Band combinations and spectral enhancements of image properties such as colour, tone, brightness, structure, location and association (Dekker, 2004; Lillesand and Kiefer, 2000) were used to aid land use boundary adjustments. Other topographic layers such as contours, rivers, roads, and villages were used to refine boundary determinations. The adjusted boundaries were overlaid with AGSYS, PNGRIS and FIMS layers to detect and resolve conflicts such as geometric overlaps, attribute mismatch, or boundary inconsistencies and edited in ArcMap.

The land use layers and RMU were overlaid through union GIS spatial operation. The composite of all layers contained data for querying and analyses. The attribute table of the composite layer was imported into MS Access and SQL queries were designed to extract information on population and agricultural land use changes by province, districts and for different environmental factors such as soil quality, slope, altitude and rainfall.

Calculating the spatial correlation surfaces between population change and transitions from one land use category to another (hereafter referred to as "from→to") was done using custom avenue script in ArcView. This script uses a moving window to compute surface of correlation coefficients between two grid themes. The size of the moving window was set to 16 km (156 cells or measurements) and the overlapping area was 5 km between windows. The percentage of maximum no-data for each moving window was 10%. The grid cell size was 1 × 1 km.

3. Results

3.1. General agricultural change

Agricultural land use increased considerably between 1975 and 2000 (Fig. 2). Most of the expansion occurred at the expense of primary forest, which decreased over the same period (Fig. 3). Large areas remain under forest in the Morobe Province. There is expansion in most land use types but agriculture increased more than others (Table 1). The annual gain in agricultural land use between 1975 and 1990 was 3%, compared to 0.9% between 1990 and 2000. Annual loss in forest was 0.8% between 1975 and 1990, but 0.4% between 1990 and 2000. Between 1975 and 2000, agriculture gained 15% from forest, which is the highest compared to gains in other land use types.

The population of Papua New Guinea more than doubled from 2.3 million in 1975 to 5.2 million in 2000. Average annual growth was 5.0%. The population of the Morobe Province grew from 270,700 to 539,400; an increase of 99% or 4% growth per year. The average agriculture area was 1.8 ha $person^{-1}$ in 1975, but decreased to 1.5 ha $person^{-1}$ in 2000. The forest area was more than halved, from 9.8 ha $person^{-1}$ in 1975 to 4.4 ha $person^{-1}$ in 2000. There was little change in grassland and plantations area when expressed in hectare per person.

3.2. Changes on correlation surfaces between population and land use

The relationship between population change and from→to land use changes were compared by running custom Avenue script in ArcView (Fig. 4). The correlation coefficient is scaled from −1 to 1. The results were classified in three intervals: −1 to 0.5 (strong negative correlation), −0.5 to 0.5 (no significant correlation), and 0.5 to 1 (strong positive correlation). Correlation between total population change and total land use change is strongly positive (64%) for Morobe Province. The correlation between total population and forest to agriculture change is 31%. The change between total population and forest to grassland was strong in certain districts. Total population change and grassland to agriculture change were positively correlated in highly populated areas.

3.3. Land use change and environmental conditions

Inceptisols are the dominant soils and cover about 54% of the Morobe province. We classified the soils using expert knowledge in which soil physical and chemical

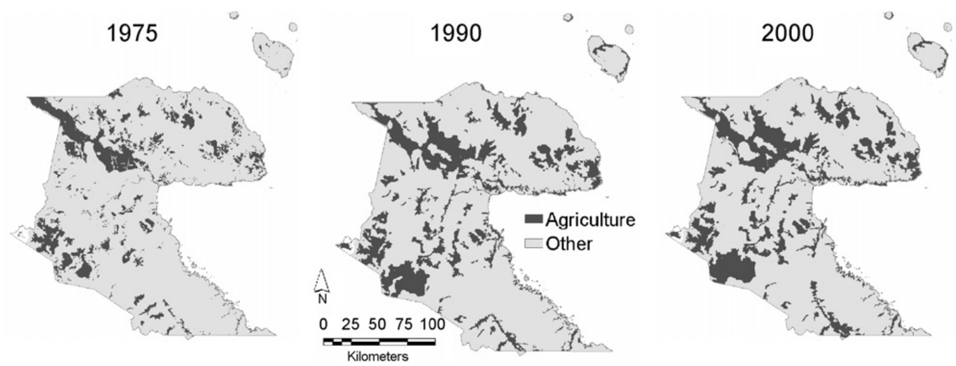

Fig. 2. Agricultural land use in 1975, 1990 and 2000 in the Morobe province of Papua New Guinea.

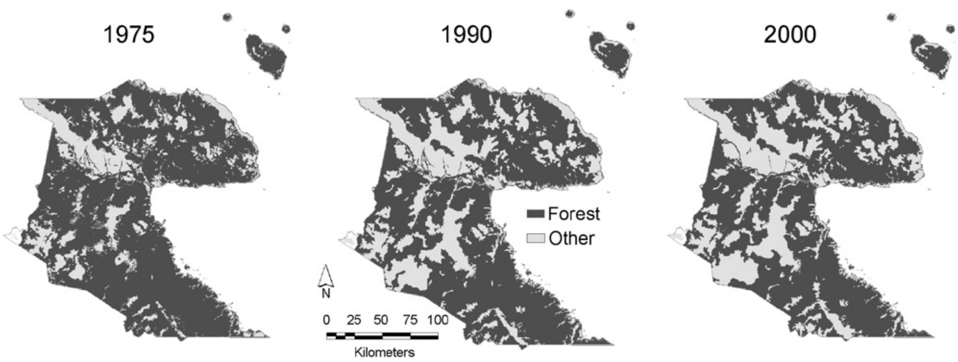

Fig. 3. Forest cover in 1975, 1990 and 2000 in the Morobe province of Papua New Guinea.

properties were classified in three categories (poor, moderate, good), and found that about 41% of the Morobe province has soils of good quality and 53% soils of moderate quality. More than 50% of the Morobe province has steep to very steep slopes; 55% of the province is below 1200 m a.s.l. Precipitation in about 55% of the province is moderately wet (1000–2500 mm year^{-1}), 33% wet (2500–4000 mm year^{-1}) and 12% very wet (>400 mm year^{-1}) (Table 2).

Table 1
Land use (in 1000 ha) in the Morobe Province of Papua New Guinea in 1975, 1990 and 2000, based on topographic maps (1975) and Landsat images (1990 and 2000)

Land use	1975		1990		2000	
	× 1000 ha	%	× 1000 ha	%	× 1000 ha	%
Agriculture	500.1	15	726.6	21	791.8	23
Forest	2646.3	78	2317.0	68	2228.7	66
Grassland	216.9	6	276.4	8	294.5	9
Plantation	23.7	1	63.2	2	67.8	2
Urban	2.5	<0.1	6.4	<0.1	6.7	<0.1
Water	3.7	<0.1	3.8	<0.1	3.9	<0.1
Total	3393.3	100	3393.3	100	3393.3	100

Relating agricultural change to the environmental conditions shows that most of the change occurred in moderately wet to very wet areas (>2500 mm rain year^{-1}), with fertile soil and on moderate to very steep slopes (10–56%). Agricultural areas that are converted to other land use are mostly Mollisols, in areas with about 1000–2500 mm rain per year.

3.4. Agricultural changes by districts

Expansion of agriculture was observed in all districts of the Morobe province. Rates of annual agricultural change ranged from 0.1% in Kaiapit to 10.3% in Siassi (Table 3). Other districts that showed a significant change in agriculture are Wau, Mumeng, Lae, Huon and Menyamya. While agricultural areas per person decreased with increasing population for most districts, Siassi and Wau districts showed an increase in agricultural area per person. Significant increases in agricultural changes on steep slopes are observed in Huon, Menyamya and Mumeng districts, while Siassi experienced a decline in land under agriculture in steeper areas.

The relationship between population growth and agricultural change by district showed that the largest change occurred in the Huon District. Menyamya, Wau and

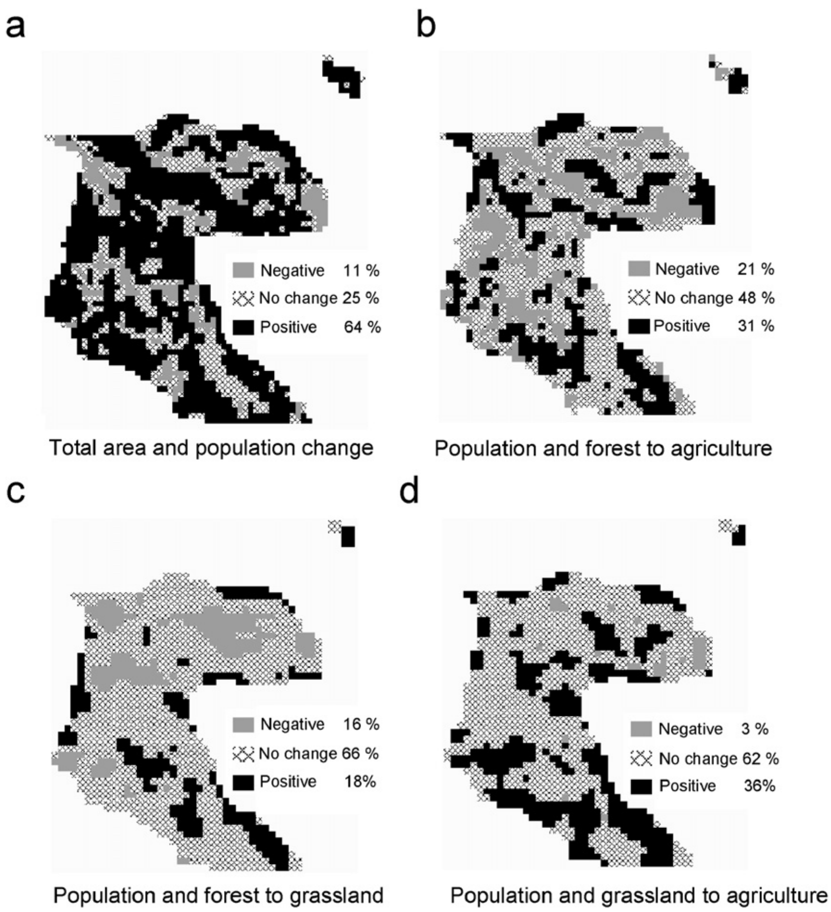

Fig. 4. Surface correlation changes between (a) population and total area, (b) population and forest to agriculture, (c) population and forest to grassland, and (d) population and grassland to agriculture.

Table 2
Environmental conditions and land use change in the Morobe Province of Papua New Guinea between 1975 and 2000

	Classes		Morobe province (× 1000 ha)		Agriculture in 1975 (× 1000 ha)		Agriculture in 2000 (× 1000 ha)		Change in agriculture (%)	
			Area	%	Area	%	Area	%	Total	Annual
Soil order	Alfisols		40.9	1	8.2	2	10.0	1	23	0.9
	Entisols		1170.9	35	181.0	36	261.8	33	45	1.8
	Inceptisols		1833.0	54	196.5	39	403.8	52	106	4.2
	Mollisols		340.0	10	113.4	23	110.8	14	−2	−0.1
	Other soils		8.4	<1						
Soil quality	Poor		199.9	6	26.3	5	40.9	5	56	2.2
	Moderate		1788.1	53	247.4	50	447.18	57	81	3.2
	Good		1395.2	41	225.4	45	298.5	38	32	1.3
Slope	Gentle	Up to 10%	408.9	12	141.9	28	160.7	20	13	0.5
	Moderate	10–34%	519.2	15	45.9	9	82.7	11	80	3.2
	Steep	35–56%	1622.0	48	218.7	44	371.4	47	70	2.8
	Very steep	>56%	843.2	25	92.6	19	171.8	22	85	3.4
Altitude	Low	0–1200 m	1875.0	55	327.8	66	520.4	66	59	2.4
	Moderate	1200–2400 m	1295.5	38	169.6	34	262.9	33	55	2.2
	High	>2400 m	222.8	7	1.7	<1	3.2	<1	83	3.3
Rainfall (mm)	Dry	1000–2500	1859.3	55	350.7	70	460.1	58	31	−16.8
	Moderate	2500–4000	1138.2	33	88.3	18	193.00	25	119	38.7
	Wet	>4000	395.8	12	60.1	12	133.4	17	122	40.9

Data source: PNGRIS.

Table 3
Agricultural area in 1975 and 2000 with rate of changes by districts in the Morobe Province of Papua New Guinea

	1975		2000		Rate of change (% year^{-1})	
District	ha	ha person^{-1}	ha	ha person^{-1}	ha	ha person^{-1}
Finschhafen	50,497	1.3	84,793	1.3	2.7	0.0
Huon	120,344	1.5	212,185	1.2	3.1	−0.7
Kabwum	42,427	1.3	61,349	1.2	1.8	−0.4
Kaiapit	120,386	5.4	123,061	3.5	0.1	−1.4
Lae	3258	0.2	6119	0.2	3.5	−1.1
Menyamya	95,298	2.6	157,679	2.4	2.6	−0.4
Mumeng	15,105	1.2	28,824	1.2	3.6	−0.2
Siassi	3763	0.5	13,472	1.0	10.3	4.1
Wau	47,980	1.8	99,297	1.9	4.3	0.1

Finschhafen districts show moderate changes while the other districts show less moderate changes. Population growth with no corresponding significant changes in agriculture is observed in Lae and Kaiapit districts (Fig. 5). The total agricultural change for the Morobe province between 1975 and 2000 was 58%, of which 6% occurred within logged-over areas where forest has been cleared for commercial logging. Agricultural changes within the logged areas tend to appear at gentler slopes, in the vicinity of populated places (villages) and in close proximity to transport access (road/sea). Fig. 6 shows a typical example on Siassi Island where agricultural changes occurred on the fringes of logged-over areas and on gentle slopes.

4. Discussion

Significant agricultural expansion was found between 1975 and 2000 and this coincides with rapid population growth. Forest is cleared for agriculture as a result of increasing population density, migrations, general economic situation or access to land resources. About 6% of the agricultural changes occur within logged-over areas. Marked agricultural changes are in close proximity to villages where land use intensity tends to be high (Bourke et al., 1998) or within easy access to transport (Kok, 2004). Clearing of forest takes place in populated areas, or that are closer to transportation access and are suitable for agriculture.

There was a significant difference in the annual agricultural land use change between 1975 and 1990 (3%) compared to 1990 and 2000 (0.9%). Land use changes are caused by a series of factors and often show a non-linear pattern over time (Lambin et al., 2003; Lepers et al., 2005). Although we have no data to investigate the differences between 1975–1990 and 1990–2000, the lower agricultural expansion between 1990 and 2000 was possibly caused by

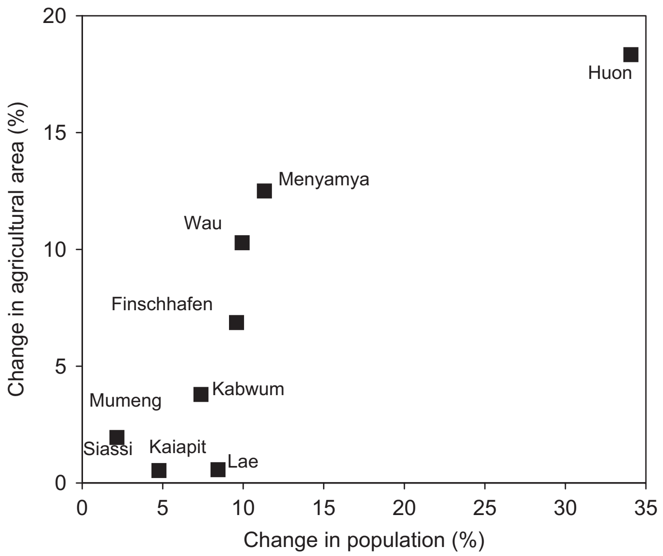

Fig. 5. Relation between changes in agricultural land use and population between 1975 and 2000 in 9 districts of the Morobe Province of Papua New Guinea.

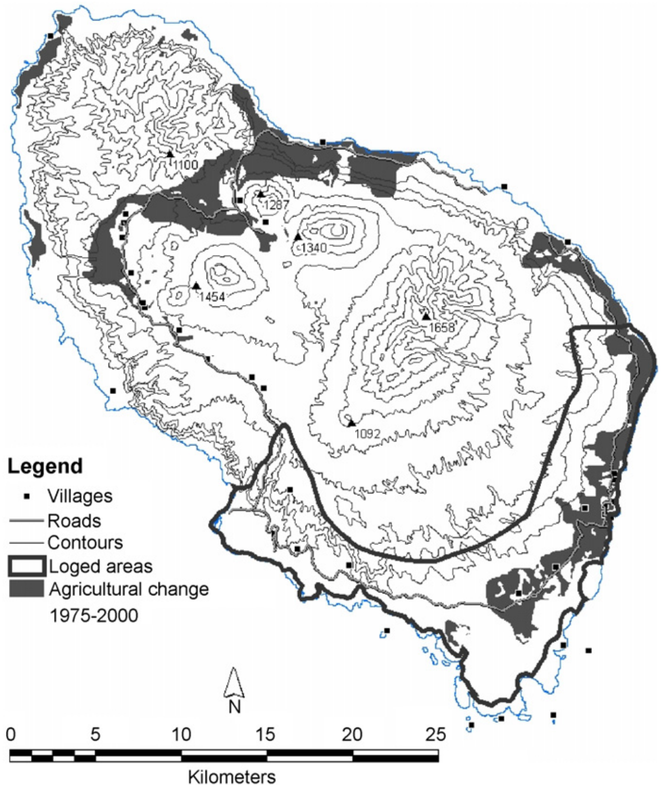

Fig. 6. Agricultural land use change between 1975 and 2000 on the fringes of logged over areas on Siassi Island in the Morobe Province of Papua New Guinea.

increased access to alternate food sources such as store and market, and increased off-farm income leading to less crop cultivation. Much of Papua New Guinea was affected by frost and drought during the 1997–1998 El Niño phenomena (Bourke, 2000) which concomitantly increased import of grains (Blakeney and Cough, 2000; Bourke, 2000; Gwaiseuk, 2000) and perhaps reduced the area under cultivation.

The correlation of total population and forest to grassland conversion is positive in certain areas. When superimposed with forestry data, most of the changed areas appear to have been logged, which means that logged-over areas are succeeded by grassland. Also correlation between total population change and grassland to agriculture conversion shows a positive relationship in highly populated areas. In the logged-over areas, grassland succeeds logging but it is subsequently converted to agriculture land. Such sequence of conversions (forest–grassland–cropland) are common in many tropical regions (Lepers et al., 2005).

The strong positive correlation between total population change and total land use change could imply lack of technological development as new areas are cleared to increase crop production rather than improving current farming techniques. People adapt to environmental conditions in the absence of technology by improving their farming techniques such as introducing new crops or mixed cropping (Bourke, 2001; Ohtsuka, 1995). Without improved farming or soil fertility management techniques, the observed land use change may affect the sustainability of agricultural production as a result of soil fertility depletion (Hartemink and Bourke, 2000). There was also increased cultivation on steeper slopes with increased risk of soil erosion; it confirms other studies in tropical regions (e.g. Kok, 2004; Pahari et al., 2001; Pfeffer et al., 2005).

There was variation in land use change between the districts of the Morobe Province and three patterns were found. Firstly, Huon district had the largest change in both population growth and agricultural land use. This could be due to better access to transport and agro-ecological conditions which allowed for a rapid population growth and an increase in the area under agriculture. Most of the district is suitable for agriculture especially along the coast and Markham valley. It is commonly found that areas with good transport access (sea, land, air) experience more change (Verburg et al., 2004).

The second group of districts (Menyamya, Wau and Finschhafen) show moderate changes. Generally, these districts have difficult terrains for accessibility but also have high agricultural potential. Menyamya is known for coffee production with other food crops due to its favourable climatic conditions, high rainfall and some fertile soils. The same applies for parts of Finschhafen and Wau districts. Apparently, population growth keeps pace with agricultural expansion in such areas.

The third group (Kabwum, Mumeng, Siassi and Kaiapit) show varying changes between 5% and 10% for agriculture and population, respectively. Mumeng, Kabwum and Kaiapit experienced more population growth compared to agriculture change which can be caused by location specific agro-ecological situations, access to transport and off-farm activities. Kaiapit is the district with the lowest agriculture change (0.1%) and the mountainous terrain constraints agricultural expansion.

5. Conclusion

The area under agriculture in the Morobe province increased by 58% while population almost doubled between 1975 and 2000. The area under agriculture was 1.5 ha person^{-1} in 2000, compared to the global average of 0.35 ha person^{-1} (Ramankutty et al., 2002). Most of the agricultural growth was observed in wet fertile areas but also on steep slopes. Increase in population density slightly reduced the per capita arable land but imposes pressure on the environment. In the absence of improved soil fertility management, improved farming system and increased crop production, the current trend of increasing the agriculture area as a result of human population growth is likely to continue.

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