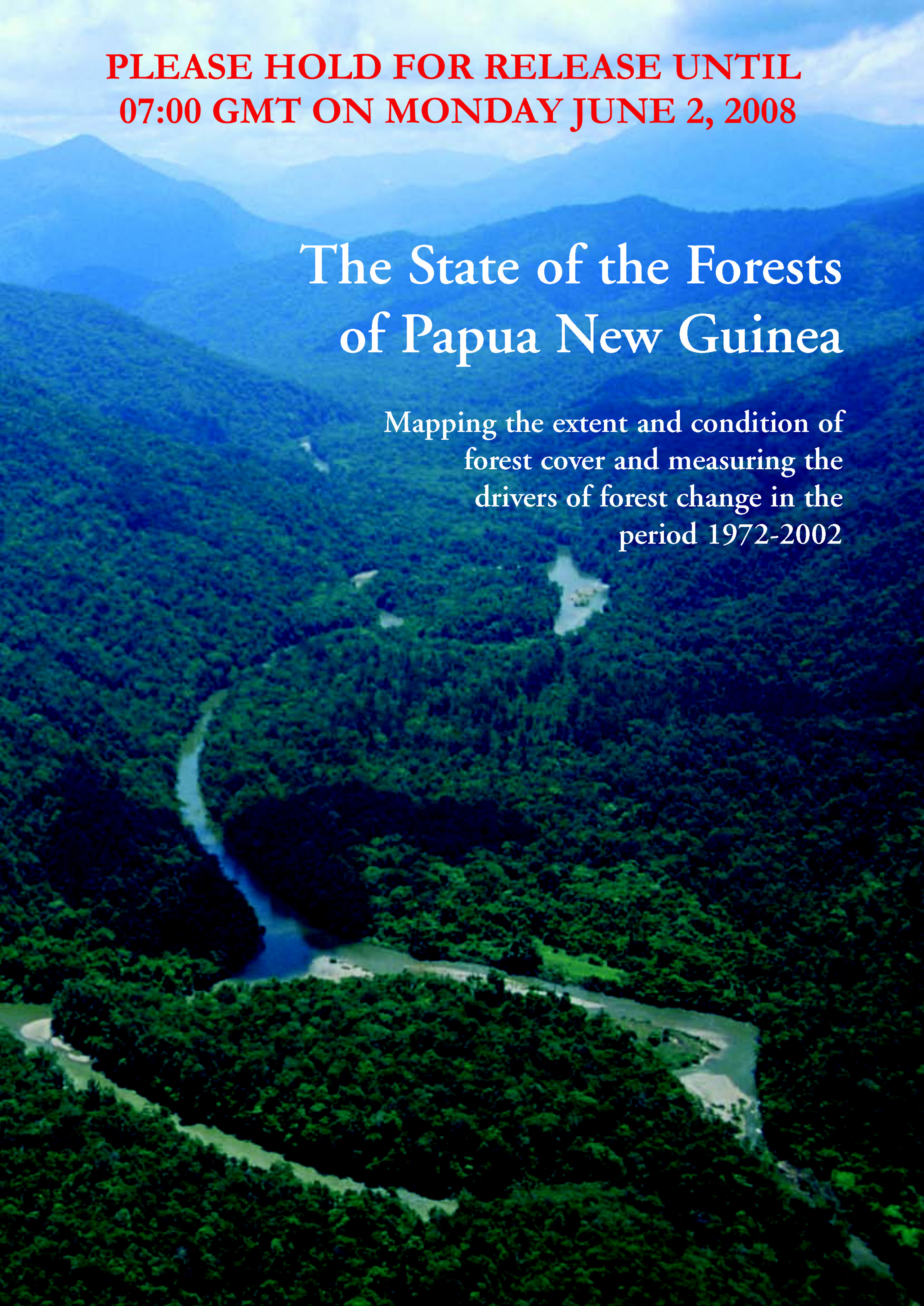

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The State of the Forests of Papua New Guinea

Mapping the extent and condition of forest cover and measuring the drivers of forest change in the period 1972-2002

Published by the University of Papua New Guinea, Port Moresby, Papua New Guinea.

Acknowledgements:

The authors would like to thank L. Ramalho, H. Sakaguchi and A. Crassner for their initiation of this work. We would also like to thank the following individuals whose support for this work was instrumental in its completion; B. McGrath, D. Freyne, L. Hill, R. Hynes, M. Graff, A. Dell'Arricia, T. King and N. Ambrosia. Funding for this project was provided by the European Union, the German Development Service and the United Nations Development Program and the support of these organisations is gratefully acknowledged.

Bibliographic reference:

Shearman, P.L., Bryan, J.E., Ash, J., Hunnam, P., Mackey, B. and Lokes, B., 2008. The State of the Forests of Papua New Guinea. Mapping the extent and condition of forest cover and measuring the drivers of forest change in the period 1972-2002. University of Papua New Guinea, 2008.

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ISBN: 9980-937-48-3

Design and typesetting by Shearman and Uramina and Nelson Ltd.
PO Box 6896, Boroko,
Port Moresby, Papua New Guinea.
Printed by Birdwing Printing.

Contact: UPNG Remote Sensing Centre,
PO Box 320, University,
NCD, Papua New Guinea.
Email: rscentre@upng.ac.pg

Cover image: The junction of the Frieda and Nena Rivers, West Sepik Province
Inside cover images: Lower montane forest in the Kikori region, Gulf Province

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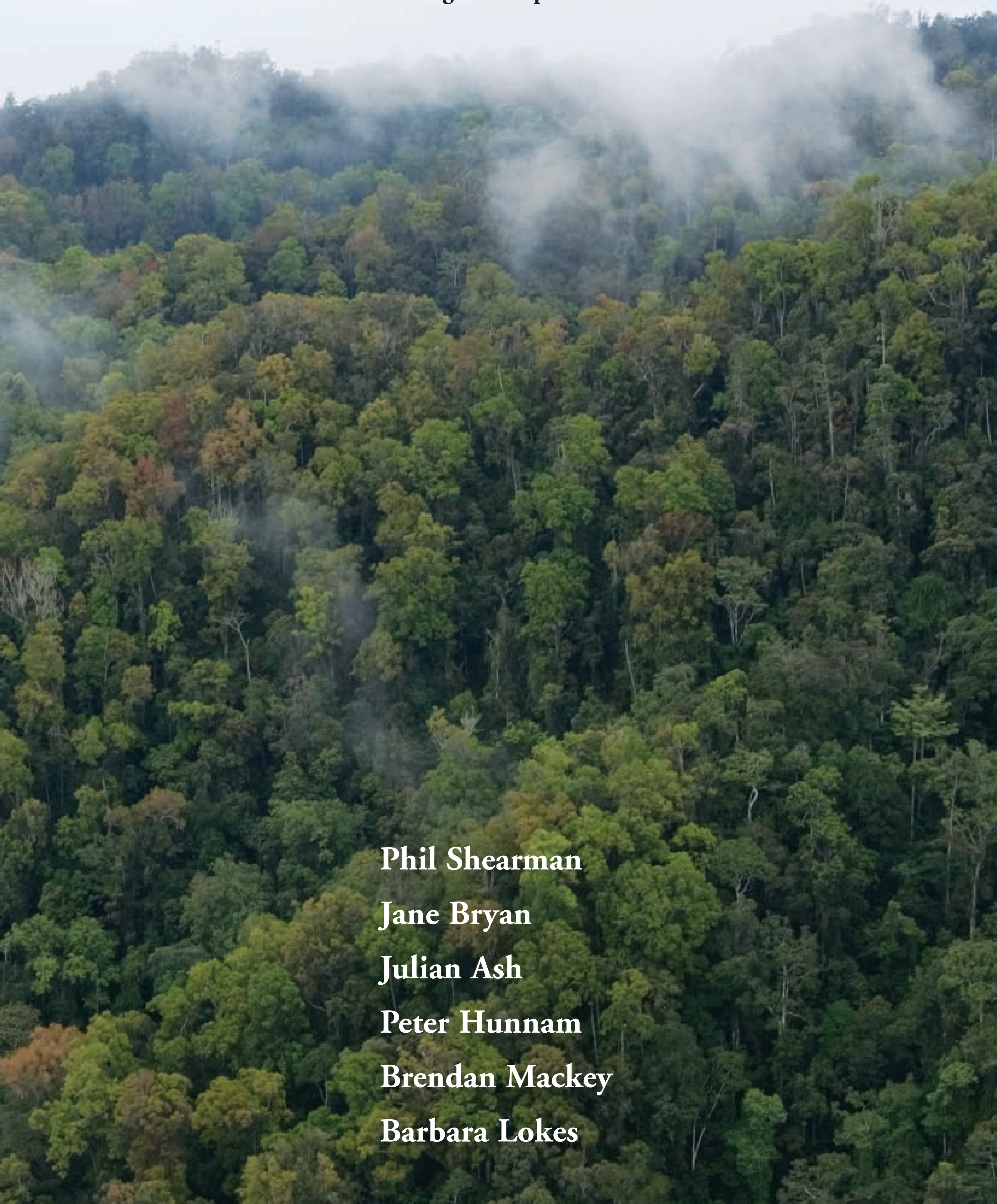

Phil Shearman

Jane Bryan

Julian Ash

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Brendan Mackey

Barbara Lokes

Papua New Guinea

As the Minister for Forests, an owner of timber resources and as a custodian of my clan's lands in the Bewani area, forests are central to my concerns. Papua New Guinea is a forested nation – forests are the natural cover of our land. Our history, our lives and our future are intimately entwined with forests.

This report on the state of our forests is the culmination of several years work by the University of Papua New Guinea. It is the first time that such an assessment has been made using digital high-resolution satellite imagery – it is the most current and detailed examination of our forests to date. Although staff of the PNG Forest Authority have been periodically involved in the creation of the data necessary for the report, the majority of the task was completed by the UPNG. It is a major contribution.

I have no doubt that this report will be controversial. Its findings and recommendations will make many people uncomfortable. Over the past decades we have imagined that our forests are limitless – perhaps the rapid modernisation that has occurred in PNG has made us reticent to accept the notions of scarcity – perhaps we have been too focussed on local developments to see the big picture. Regardless, if this report is the bitter pill that we need to swallow to ensure that we maintain our forests into the foreseeable future, so be it.

The good news? We are still an extensively forested country. We still have options on the table for consideration – the future has not been already pre-determined by our past actions. The bad news? We are losing our forests at rates comparable with other tropical nations – especially in the lowlands. We urgently need to focus on ensuring that our logged forests regenerate adequately, that commercial forestry moves towards sustainability and we need to examine the provision of agricultural extension such that forest loss from subsistence activities can be stemmed. I agree with the notion that 'conservation' is not just the preserve of the creation of protected areas. If in 50 years, PNG is left only with scraps of forest inside National Parks, then we have all failed. However this is the end-point of the path upon which are currently walking.

We need to imagine a future in which forest loss is not inevitable – a future in which it should be possible for us to have more forest than we do now. Forests are valuable resources, and managed correctly are renewable resources. We will need them to support us long after the minerals are gone.

For these reasons I am proud to endorse this publication.

The Honourable Belden Namah MP
Minster for Forests

Preface

Papua New Guinea is an island nation that sits just to the north of Australia at the junction of South East Asia and the Pacific Islands. Forests are the dominant feature of the country's ecology extending over 33 million hectares of rugged landscape to govern the flow of water and energy and all other ecosystem processes. An astounding diversity of plant and animal life has evolved in these forests; perhaps 6-7 % of the world's species in a land area less than half of one per cent of the world's total. This rich living resource provides the essential foundation for the lives, diverse cultures, livelihoods and economy of Papua New Guinea's peoples.

In order to exploit PNG's natural resources wisely and sustainably, to manage the economy and development of the nation, to protect ecological processes and conserve biological diversity, and to safeguard the cultures and livelihoods of six million Papua New Guineans, it is important to know the extent and condition of the national forest estate and the location and area of each forest type. It is also essential to measure changes that occur to the forest resources, and to understand and regulate the drivers of these changes.

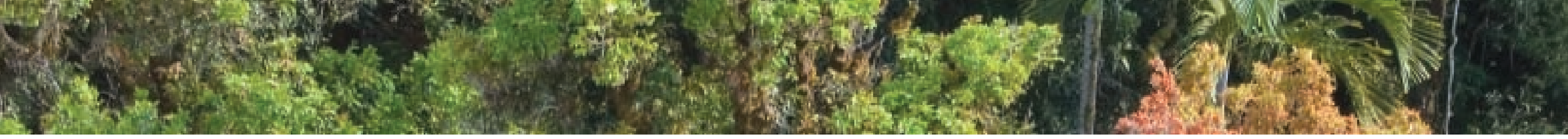
To date, knowledge of Papua New Guinea's forests has been patchy and imprecise. Policy makers, forest managers and conservationists have not had comprehensive information to guide their efforts or to evaluate their decisions. This has often resulted in an inadequate and ineffectual regime of forest governance and management.

Previous attempts to estimate forest cover, condition and especially change have foundered on the difficulties of measuring fine-scale patterns of vegetation and localised change, which are made much more difficult by the rugged topography and persistent cloud cover that characterise PNG.

For the past five years, a small team at the University of Papua New Guinea has worked out solutions to these problems. They have developed techniques for the analysis of high-resolution satellite imagery, electronic pattern recognition software, and spatially accurate mapping, in order to resolve forest types, boundaries and change in closed forests at the precision of a few tens of metres. The techniques applied provide an accurate base for evaluating the current state of the forest landscape of PNG, and for measuring where change has occurred. Additional data sets have been analysed to determine the causes and rates of the documented changes.

This document presents a summary of the results of this research and provides positive prescriptions to improve the quality of future forest management policy.

Contents



The State of the Forests Study

Since 2003, the University of Papua New Guinea Remote Sensing Centre has prepared and analysed comprehensive data-sets on the state of the country's forests from the early 1970s, centred on 1972, and from the early 2000s, centred on 2002. This report presents its findings on the past and current extents of Papua New Guinea's intact forests, the rates of forest changes across Papua New Guinea over the period of the past thirty years, and discusses the causes and implications of these losses for the country's national forest estate. The report focuses on quantification of the gross changes that have occurred through the conversion of intact forest to degraded logged forest, garden and fallow land, grassland, plantation and other non-forest classes.

The present study is the first to analyse deforestation and degradation across the whole country at a scale and precision able to discern the effects of each of the major drivers of forest change. This required the development of techniques that are robust over the broad variety of terrain and vegetation and the frequent cloud cover that prevails in PNG. Analysis of changes to land cover presents many challenges, especially when the older baseline maps (1970s) and the new satellite imagery (2000s) are based on different types of information; the combination in PNG is perhaps unique and required the development and application of novel methods.

Deforestation and forest degradation can only be adequately quantified and monitored across a large geographical area using high-resolution satellite imagery. This requires the comparison of precisely located imagery showing appropriately classified vegetation types recorded at different times (Asner et al, 2005). This study mapped recent (2002) forest extent and degradation using high-resolution Landsat ETM+ and SPOT4 & SPOT 5 imagery. The resulting 2002 forest map was compared with a baseline high-resolution 1972 forest map allowing the measurement of the 30-year net area of deforestation and degradation across PNG. Various methods were employed to identify the individual causes of areas where forest change had occurred. These data were used to estimate recent net deforestation and degradation rates. The methods employed by this study are detailed in Annex 2.

The study distinguishes commercial logging, subsistence cultivation and burning as the major drivers of forest change across PNG over the past thirty years. The analysis determines accurately for the first time the impacts of subsistence agriculture and of logging activities on forest cover in each region and province. These data are essential for the rational planning and management of future land and forest use, food production, conservation and development in Papua New Guinea.

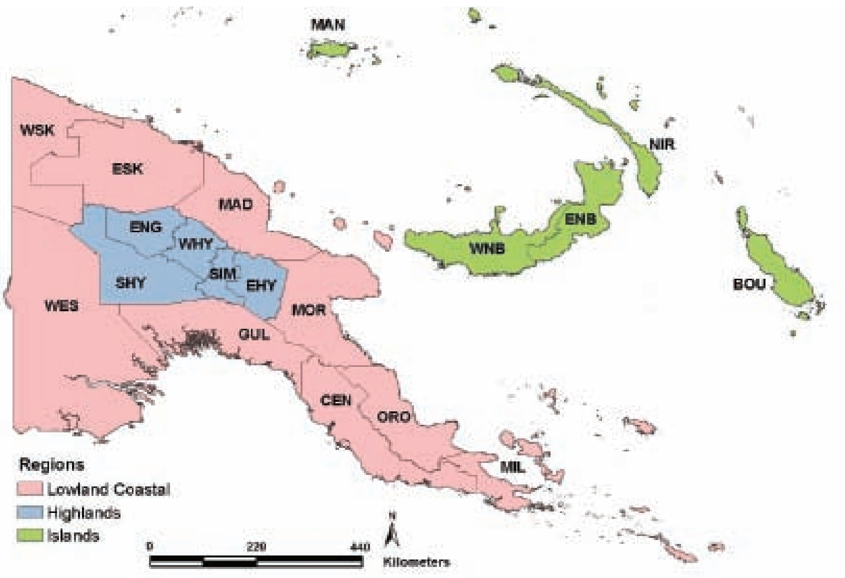
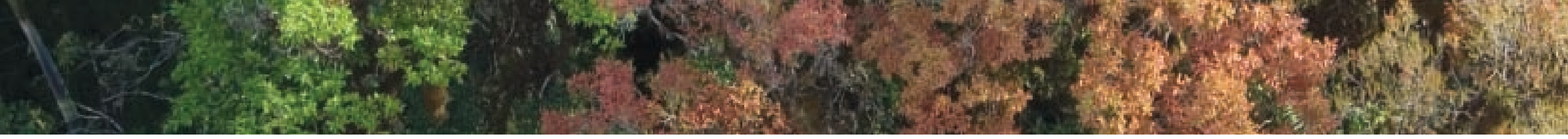


Figure 1: A map of Papua New Guinea showing provincial boundaries and general regions. Each province is shown coloured by the broad region in which it is situated, the Islands, the Highlands or the Mainland Lowland region. Provincial abbreviations: Bougainville (BOU); Central (CEN); Eastern Highlands (EHY); East New Britain (ENB); Enga (ENG); East Sepik (ESK); Gulf (GUL); Madang (MAD); Manus (MAN); Milne Bay (MIL); Morobe (MOR); New Ireland (NIR); Oro (ORO); Southern Highlands (SHY); Chimbu (SIM); Western (WES); Western Highlands (WHY); West New Britain (WNB); West Sepik (WSK).



Summary of Main Findings

The study of forest change across Papua New Guinea records that extensive and rapid deforestation and forest degradation have occurred over the thirty years from 1972 to 2002. The main human activities driving these changes are identified as commercial forestry, subsistence agriculture, fires, and the development and operations of mines and plantations.

The most significant findings of the study are as follows:

- ❖ Change in the extent and condition in PNG's forests is occurring considerably faster than previously recorded – it is estimated that in 2002, 1.41% of Papua New Guinea's tropical forests were being deforested or degraded annually.
- ❖ By 2002 primary forests accessible to mechanized logging were being degraded or cleared at the rate of 2.6% per annum. In 2001 approximately 362,400 hectares of these forests were deforested or degraded. Of the 1972 commercially accessible forest area, it is estimated that by 2021, 83% will have been cleared or degraded if current trends continue.
- ❖ Forests are being logged repeatedly and wastefully, with little regard for forest ecology, ecosystem functions or silvicultural practices which reduce impact and enhance regeneration. Across the Mainland lowland and Islands regions, logged forests have in many locations been reduced to a state that is highly vulnerable to further degradation and eventual conversion.
- ❖ The management of PNG's forestry industry has paid little attention to the concept of sustainability in planning forest management and accessing forest land, nor to measures to ensure low impacts, good silvicultural practices, biodiversity conservation, equitable access and sharing of benefits from resource exploitation.
- ❖ The area of PNG's globally important montane forests has been significantly reduced through burning, largely associated with fires occurring during periods of drought.
- ❖ Current conservation measures, through forest management practices or site or species protection, are inadequate. Neither the formal protected areas system (Wildlife Management Areas and National Parks), nor local efforts to combine conservation and resource-based development activities, supported by land-owners, conservation organisations and the national government's conservation agency, have safeguarded the forest resources they encompass.
- ❖ PNG forests could make a significant contribution to global efforts to combat climate change and it is in PNG's own interests to do so as the nation is particularly susceptible to its negative impacts. However, the current state of forest management and lack of effective governance means that PNG is a long way from being able to meaningfully participate in the carbon economy.
- ❖ This report concludes by advocating substantial reforms to PNG's forest and land management regime, stressing the urgent need for Papua New Guinea to strengthen natural resource governance, support for local landowners and community initiatives, sound silvicultural practices, biodiversity conservation and integrated catchment management, in order to achieve some degree of essential conservation, sustainability and security. Such changes will provide a framework in which PNG can begin to realize its own National Goals as set out in its Constitution.

Chapter 1

The Current State of the Forests of Papua New Guinea

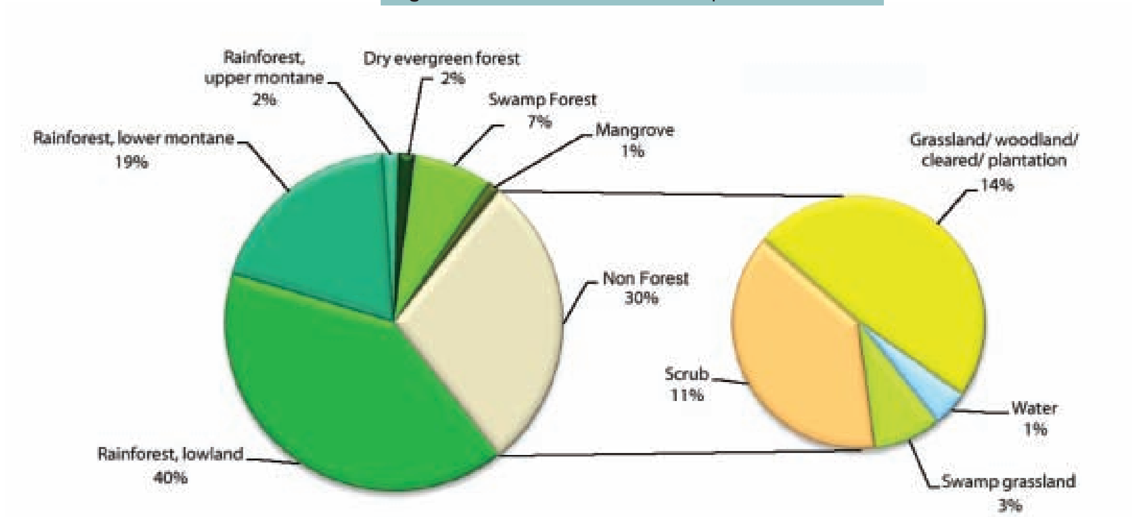
This study confirms precisely the extent and the outstanding significance – nationally, regionally and globally – of Papua New Guinea's forests.

PNG's total land area is 46.17 million hectares (ha), of which 40.53 million ha are the eastern half of the main island of New Guinea and 5.64 million ha are the Island provinces to the east, which include the large islands of New Britain, New Ireland, Bougainville and Manus and several hundred smaller islands.

The land-cover maps prepared through this study record that in 2002, 71% of this land area was covered by forest, a total of 33 million ha of diverse tropical lowland and montane rainforest, swamp forest, dry evergreen forest and mangroves. This high proportion of forested land area emphasises the importance of forest to Papua New Guinea, historically perhaps the most forested land in the world. However, the study also records that by 2002, 2.92 million ha of forest land had been degraded by logging, and that this secondary forest is vulnerable to further degradation and conversion.

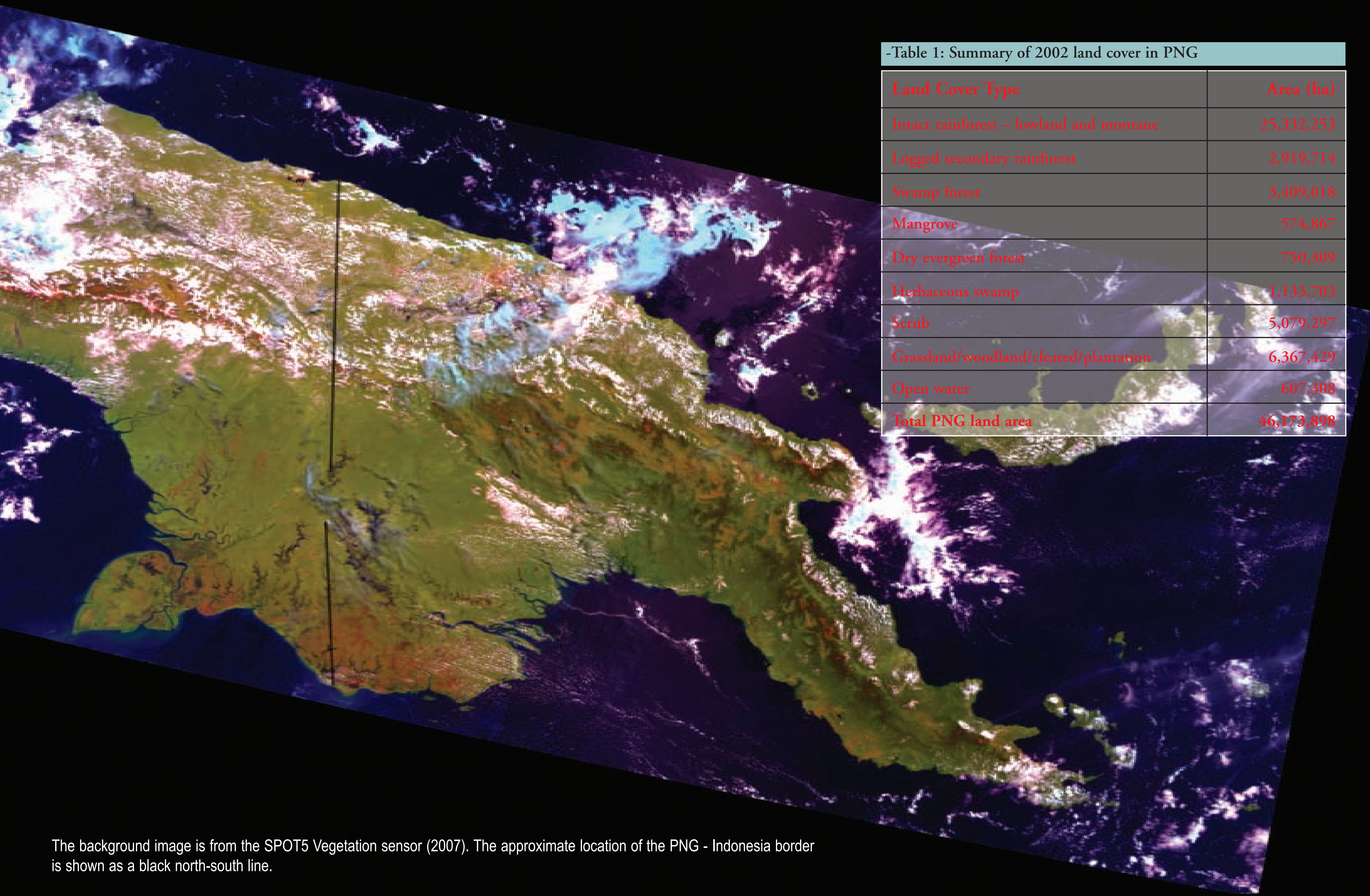
The area of PNG's land-cover types in 2002 is presented in Figure 2 and Table 1.

Figure 2: 2002 Land-cover of Papua New Guinea.



-Table 1: Summary of 2002 land cover in PNG

Land Cover Type	Area (ha)
Intact rainforest – lowland and montane	25,332,253
Logged secondary rainforest	2,919,714
Swamp forest	3,409,018
Mangrove	574,867
Dry evergreen forest	750,309
Herbaceous swamp	1,133,703
Scrub	5,079,297
Grassland/woodland/cleared/plantation	6,367,429
Open water	607,308
Total PNG land area	**46,173,898**

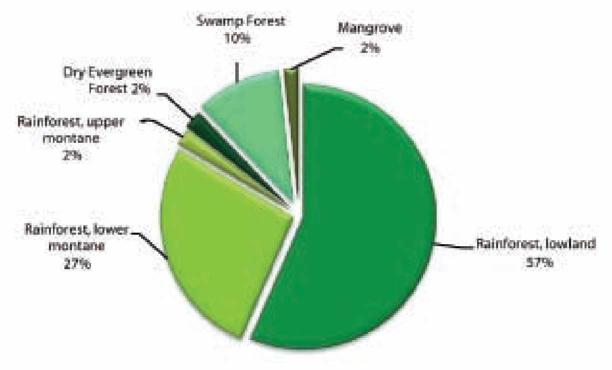


The background image is from the SPOT5 Vegetation sensor (2007). The approximate location of the PNG - Indonesia border is shown as a black north-south line.

The extent of PNG's main forest types

The 2002 data confirm that the major, broad category of rainforest comprises 86% of PNG's forests, forming the predominant land cover of PNG, with over 28 million hectares cloaking approximately 61% of the land. Rainforest occurs as lowland forest across the coastal plains and foothills, up to 1,000 metres above sea level, and as montane forest above that altitude, through the country's main ranges and along the central cordillera to the West Papuan border.

Figure 3: 2002 Forest cover.



Lowland rainforest (<1000 m altitude) forms more than half (57%) of the total forest cover of the country and contains the country's important commercial forest types. A key finding of the change analysis was that by 2002, more than 15% of this vital resource was degraded secondary forest as a consequence of relatively recent logging activity. This area, totalling 2.9 million hectares, is also considered to be at high risk of conversion to non-forest cover.

Lower montane (1,000 – 2,800 m altitude) and ***Upper montane forest*** (> 2,800 m altitude[1]) are endemic-rich rainforests generally located in steep, rugged terrain. Their high levels of species endemism make PNG's montane forests of global significance for biodiversity conservation. In 2002, there were over 8,910,600 ha of lower montane forest and 702,300 ha of upper montane forest respectively in PNG.

Swamp forests are a major component of PNG's extensive lowlands and coastal zone, covering a total of 3.4 million hectares, occurring close to water courses in flat areas that are permanently or seasonally inundated, and where valleys and water flow become blocked by silt and vegetation. Over 80% of PNG's swamp forests have developed in the East and West Sepik, and Western and Gulf Provinces, associated with the country's two major catchments of the Sepik and the Fly rivers. Swamp forests are valuable habitats for conservation and it is significant that they are often difficult to access and therefore remain to a large extent undisturbed. PNG, unlike Indonesia, has not yet embarked upon any mechanised drainage of swamp forests to enable agricultural activities to take place, and the present study also highlights the inaccessibility of swamp forests to mechanised logging. Nevertheless, swamp forest in PNG is vulnerable to major environmental damage, as documented in the Ok Tedi river region where overbank deposition of mine tailings has resulted in the dieback of up to 150,000 hectares of swamp forest and rainforest (Higgins, 2002).

Dry evergreen forests: The analysis confirmed that PNG contains the largest tract of dry evergreen forest in the SE Asian region, with 2002 coverage estimated at 750,300 ha, confined to Western Province's seasonally-dry Trans-Fly area, to the south-west of the lower Fly river.

Mangrove forests: The study also mapped 574,867 hectares of mangrove forests in PNG in 2002, fringing relatively sheltered and shallow stretches of the coastline. All of the coastal provinces have some mangroves, but 66% of the total were found in the Gulf and Western Provinces, where the most extensive stands occur around the head of the Gulf of Papua and along the coast of the Trans-Fly area, west of the Fly river delta towards West Papua.

The study used the 2002 land-cover maps to measure the extent of each major forest type for each of the three broad regions and each of the 19 Provinces[2] that make up PNG. The results are presented in Table 2 and Figure 2.

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[1] *These altitudinal boundaries are based on Paijmans (1976) and Holdridge's Life Zones in PNG (McAlpine et al, 1983).*

[2] *The National Capital District of Port Moresby is the 20th Province-level administrative unit.*

A map of each Province is provided as Annex 4 in this report. Each map presents the 2002 land-cover classification prepared through the present study, and shows the areas that had been deforested and those degraded to secondary forest between 1972 and 2002.

Figure 4: The proportion land-cover types in the regions of PNG.

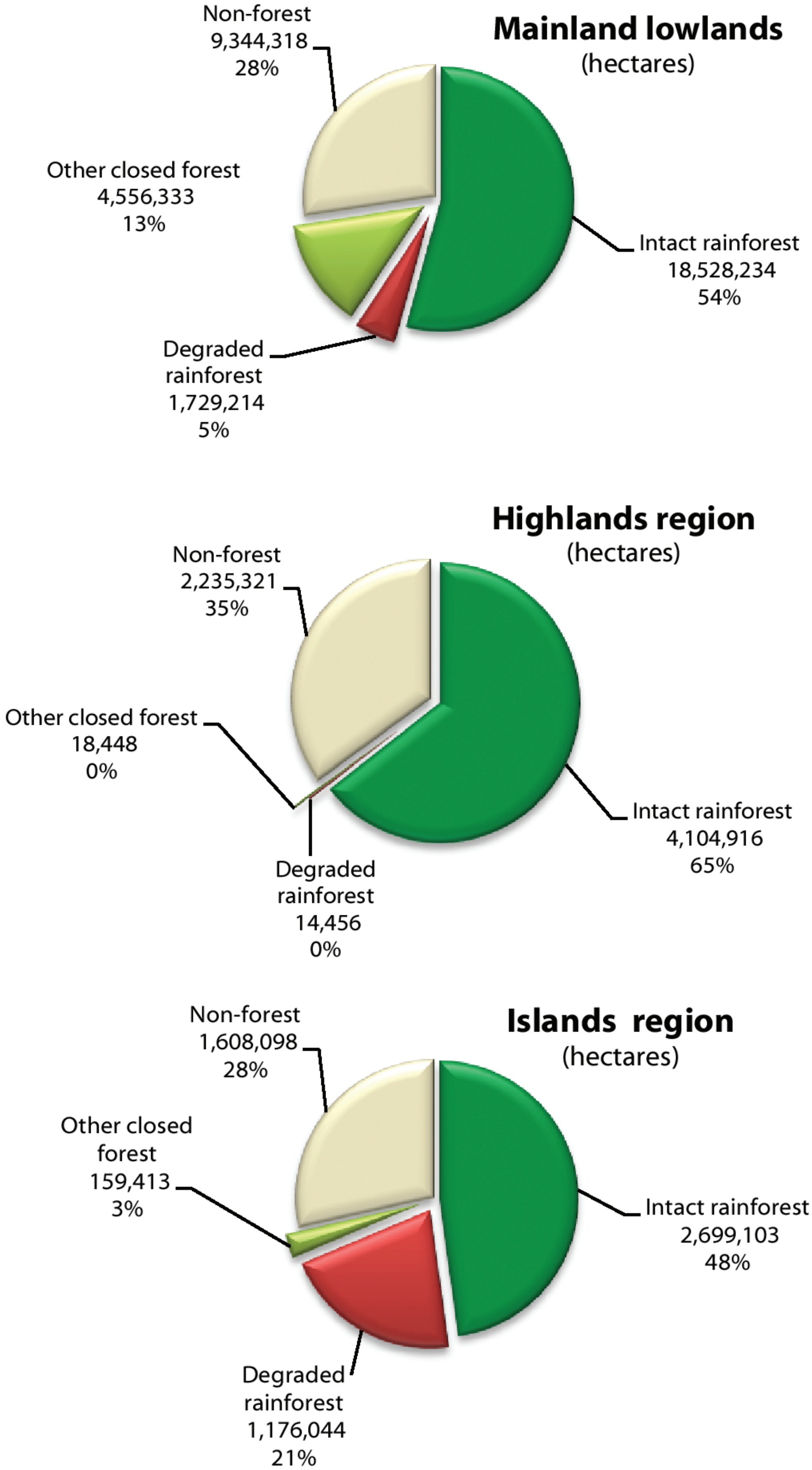


Table 2: Area (ha) of Vegetation and Land-cover types by Region and Province in 2002.

Name	Land Area	Rainforest including Degraded	*Degraded Rainforest*	Dry Evergreen	Swamp Forest	Mangrove	Herbaceous Swamp	Scrub	Grassland/ Woodland/ Cleared	Water
Western	9,811,471	4,575,048	*553,010*	750,309	1,091,282	117,623	946,191	680,834	1,475,795	174,389
Gulf	3,454,983	2,367,151	*337,182*	0	503,781	260,822	34,690	96,785	139,681	52,073
Central	2,980,233	1,963,004	*179,985*	0	64,678	59,029	44,540	322,144	506,271	20,567
Milne Bay	1,419,559	926,031	*100,630*	0	12,431	44,606	153	208,090	223,497	4,751
Oro	2,260,779	1,559,545	*90,087*	0	195,459	16,137	27,365	184,220	259,353	18,700
Morobe	3,376,192	2,096,544	*110,129*	0	54,266	3,590	5,727	495,365	687,846	32,854
Madang	2,897,006	1,994,812	*73,778*	0	91,765	812	5,294	479,893	284,393	40,037
East Sepik	4,367,102	*2,046,917*	*44,172*	0	1,064,051	19,872	64,206	387,303	637,824	146,929
West Sepik	3,590,774	2,728,396	*240,241*	0	205,037	783	459	440,143	168,769	47,187
Mainland Lowland Region	**34,158,099**	**20,257,448**	***1,729,214***	**750,309**	**3,282,750**	**523,274**	**1,128,625**	**3,294,777**	**4,383,429**	**537,487**
Southern Highlands	2,559,769	1,877,043	*7,319*	0	18,134	0	0	279,003	365,510	20,079
Enga	1,172,997	807,871	*0*	0	192	0	0	120,325	240,868	3,741
Western Highlands	912,306	498,065	*0*	0	0	0	0	142,155	268,472	3,614
Chimbu	613,360	363,714	*0*	0	122	0	0	109,581	136,766	3,177
Eastern Highlands	1,114,709	572,679	*7,137*	0	0	0	0	134,734	402,348	4,948
Highlands Region	**6,373,141**	**4,119,372**	***14,456***	**0**	**18,448**	**0**	**0**	**785,798**	**1,413,964**	**35,559**
Mainland Total	**40,531,240**	**24,376,820**	***1,743,670***	**750,309**	**3,301,198**	**523,274**	**1,128,625**	**4,080,575**	**5,797,393**	**573,046**
Manus	191,274	124,000	*21,619*	0	17,862	7,404	0	35,109	6,120	779
New Ireland	958,090	646,802	*259,397*	0	12,472	18,933	222	223,738	51,754	4,169
East New Britain	1,528,034	1,138,487	*253,110*	0	3,546	2,788	154	152,710	223,162	7,187
West New Britain	2,029,582	1,499,119	*641,918*	0	36,435	14,509	4,702	229,177	233,802	11,838
Bougainville	935,678	466,739	*0*	0	37,505	7,959	0	357,988	55,198	10,289
Islands Region	**5,642,658**	**3,875,147**	***1,176,044***	**0**	**107,820**	**51,593**	**5,078**	**998,722**	**570,036**	**34,262**
Total PNG	**46,173,898**	**28,251,967**	***2,919,714***	**750,309**	**3,409,018**	**574,867**	**1,133,703**	**5,079,297**	**6,367,429**	**607,308**

1.2 Regional and global significance of the forests of PNG

Papua New Guinea's forest ecosystems, ranging from mangroves to montane and from seasonal savannah to continuously wet cloud forest, form one of the largest and most diverse blocks of tropical forest in the world and are of the highest global conservation significance. Within Oceania, PNG has by far the greatest area of tropical rainforest, twice as much as the remainder of the region combined. The island of New Guinea as a whole (combining mainland PNG and Indonesia's West Papua region) is the largest contiguous area of forest in Asia-Pacific and the third largest tropical rainforest on the planet, after the Amazon and Congo forests (Brooks et al, 2006). These data indicate that Papua New Guinea is both regionally and globally significant in terms of forest area and diversity of forest types.

The significance of Papua New Guinea's forests is highlighted when the areas of different forest types are compared across the region in Figure 5.

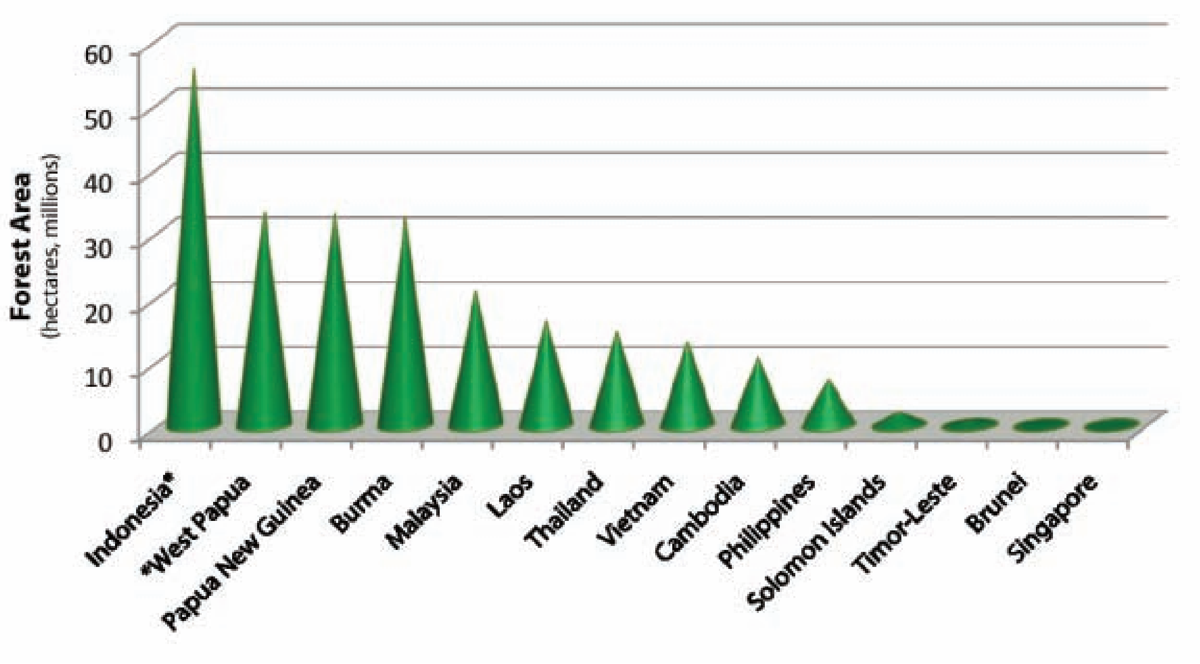


Figure 5

Area of forest in PNG compared to the Southeast Asia/Pacific region. In all countries except PNG these figures are based on data published by; FAO, 2005a; FWI/GFW, 2002; Fuller et al, 2004; and Stibig and Malingreau, 2003. Stibig and Malingreau (2003) estimated the total area of forest in insular Southeast Asia (Malaysia, Singapore, Indonesia, Brunei, Philippines and Papua New Guinea) at 158 million ha, while the FAO estimated 161 million ha in 2000 (FAO, 2000). *1997 estimate.

Table 3 summarises the high proportions of Southeast Asia's major forest types that occur in Papua New Guinea: besides 20% of the region's closed tropical forests, PNG contains 37% of the region's swamp forests and 14% of the region's mangrove forests. Of particular regional importance are PNG's montane forests, due both to their regional scarcity and high levels of endemicity. At least 37% of montane forests in the Asia-Pacific region occur in PNG. PNG's mangrove forests are the sixth most extensive of any country, while the island of New Guinea as a whole (PNG and West Papua) has by far the largest area of semi-contiguous mangroves in the world. A comparison of estimates of mangrove areas world-wide is presented in Table 4.

Table 3: Area of vegetation types in insular Southeast Asia (Stibig and Malingreau, 2003)

Vegetation Type	Area (ha)	Percent in PNG
Rainforest, mainly closed and dense	141,411,347	20
(Montane)	(26,296,378)	37
(Lowland)	(115,114,969)	16
Mangrove Forest	4,027,422	14
Swamp Forest	12,280,353	37

Table 4: Area of mangroves worldwide compared to PNG

Country	Mangrove area (ha)	Source
Indonesia	2,930,000	FAO (2003)
(West Papua)	*(1,249,052)*	Stibig and Malingreau (2003)
PNG	574,867	Present study
(New Guinea)	*(1,823,919)*	Present study; Stibig and Malingreau (2003)
Brazil	1,010,000	FAO (2003)
Nigeria	997,000	FAO (2003)
Australia	955,000	FAO (2003)
Bangladesh	622,600	FAO (2003)
Malaysia	572,100	FAO (2003)
Cuba	529,000	FAO (2003)

1.3 The values of Papua New Guinea's forests

Forests play a key role in the ecology and economy of Papua New Guinea and are significant from a global environment perspective. As highlighted by the 2002 land-cover mapping, Papua New Guinea is a forested land; its extensive, dense tropical rainforests are a dominant and integral part of its landscapes and nature. The country's forests provide vital ecological services that maintain the functioning of its land and coastal marine ecosystems, and also play a major role in the steady cycling of water and carbon dioxide, helping to regulate climatic stability (Hunt, 2006). They provide the foundation of the country's ecology, society and economy, and the source of its wealth of biological diversity, the living natural resources that have sustained the human population for at least 40,000 years.

Papua New Guinea's forests provide subsistence food – plants, animals and fungi – and building materials for a large proportion of the nation's six million people. Over the last 10,000 years agriculture has emerged as the principal source of food over much of New Guinea, relying largely on a swidden system in which patches of forest are cleared for gardens, cultivated for a few crop cycles and then abandoned as fallows in which the regenerating forest restores soil fertility. The forests are a source of building materials and also serve as an important source of food and shelter when crops fail, in times of economic crisis or conflict and when natural disasters occur. They provide a range of both local and global environmental benefits that are often overlooked and remain economically undervalued. These services include watershed protection, water filtration, coastal and reef protection, preservation of fish stocks, soil stability and fertility, aesthetic landscape benefits, and carbon sequestration.

The forests of PNG also provide commercial timber. Over recent decades, overseas demand for timber products has led to increased logging and timber exports from Papua New Guinea, to the extent that large proportions of some forest types and some regions have already been fully exploited (ODI, 2006). Recently, there has also been increased recognition that forests play a substantial role in fixing atmospheric carbon dioxide and serve as a massive carbon sink (Lewis, 2006). Recent post-Kyoto discussions acknowledge that the clearance and degradation of forests results in significant carbon emissions (Stern, 2007). This has raised the prospect of countries like PNG receiving external assistance in return for reafforestation efforts or reductions in rates of deforestation and degradation of the forest estate (Laurance, 2007).

Biodiversity values

Papua New Guinea probably harbours more than six percent of the world's biodiversity within some of the world's most biologically diverse communities (Davis et al, 1995; European Union, 2006). The lowland tropical and subtropical moist forests of New Guinea have been ranked among the world's ten most ecologically distinctive forest regions (Olsen and Dinerstein, 1998; Brooks et al, 2006; Bryant et al, 1997). The island's mangrove forests are recognised as the most extensive and species rich in the world; the tropical savannah woodlands are considered globally important because of their many endemic and restricted species; its riverine ecosystems are recognised for their high fish endemism and other distinctive species that depend on the surrounding forests.

The complex mix of forest types, wide variations in climate, and the long history of connection and then isolation from neighbouring landmasses have all contributed to a rich faunal biodiversity and high degree of endemism. PNG's forests contain at least 191 species of mammals (of which over 80% are endemic), 750 bird species (>50% are endemic), 300 species of reptiles and 197 species of amphibians, 3,000 species of fish and an estimated 200,000 to 400,000 insect species, most of which are yet to be described and classified (Sekhran and Miller, 1994).

Although the status of many vertebrate species is currently unknown, some species are extremely rare and have very limited bio-geographical distributions. The International Union for the Conservation of Nature list of most threatened animals in Papua New Guinea includes 38 species of mammals, 22 species of birds, 8 species of reptiles and 26 species of invertebrates (IUCN, 2006). Even these estimations of the diversity and status of Papua New Guinea's forests are based on knowledge that is severely limited, given the relatively superficial amount of research that has been conducted.

Non-timber forest products

Throughout humans' long existence on the mainland and islands, Papua New Guinea's forests have served a vital role in maintaining the health and well-being of the majority of the population and providing them with the means to live and, more recently, generate income. Over 80% of the population of Papua New Guinea are still directly dependent on the local environment for their subsistence and livelihoods (NSO, 2000). Forests contribute a rich variety of foods and other items essential for daily survival and economic activity, and form fertile soils for subsistence food production through the process of shifting cultivation or 'swidden' agriculture (Allen, 1985).

More than five hundred species of plants have been identified in use as food in PNG, the vast majority growing wild in either primary or secondary forest. In total, more than one thousand species of PNG's plants have been identified that are used for food, medicine, ropes, building materials, stimulants, body decoration and adornment, art, utensils and canoes (Powell, 1982).

Hunting is still a major activity for many people in rural Papua New Guinea and forms an important part of customary practice. Recent research suggests that between 4.14 to 7.9 million vertebrate animals, comprising 10.95 to 20.90 million kilograms of biomass, are consumed each year across the country (Mack and West, 2005). These animals are mostly obtained from forests. They would amount to a retail replacement value (in town, ignoring transport costs to rural areas) of approximately 75 million kina annually (US$26 million), for either tinned fish or lamb flaps – the cheapest source of meat.

Commercially-valuable non-timber forest products include resins, gums, meat for food, oils, sandalwood and rattan. Forest-related commercial opportunities exist for butterfly farming, insect farming, orchid production, crocodile hunting and deer, fish and cassowary farming as well as handicrafts and eco- and adventure tourism (Chatterton et al, 2000). The forests of Papua New Guinea also hold an as yet unassessed value in terms of their biodiversity, gene pools, potential educational services and pharmaceutical uses.

Ecological services, catchment and coastal protection

Papua New Guinea's forests perform a number of crucial ecological functions, the importance of which also tends to be underestimated and unrecognised. The broad range of these free services includes regulation of water catchments and enhancement of water quality; global, regional and microclimate stabilisation; soil and nutrient retention; insect and rodent control; crop pollination; and the maintenance of fish stocks (Primack and Corlett, 2004).

Intact and healthy forests are vital in maintaining the integrity and health of the country's river catchments (Sekhran and Miller, 1994) and for preserving water supplies and quality (Kaimowitz, 2004). Their functions include protection of watersheds, regulating water flows, maintaining soil formation and health, reducing local flooding and supplying high quality water by filtering silt and pollutants. Forested catchments supply drinking water, habitats for plants and animals, areas of natural beauty and water bodies that provide important food and energy sources. The maintenance of forests is thus strongly linked to the health and quality of life of PNG's citizens.

Papua New Guinea's landscape is dominated by forested river catchments, which are fed by heavy rainfall averaging more than 8,000 mm annually in parts of the central ranges and up to 7,000m in the Islands region (FAO AQUASTAT, 2008). Virtually all of PNG's fresh water flows via forest rivers and lakes and from forest-derived water tables. The quality of the water flowing into PNG's coastal seas and the amounts of organic and inorganic matter transported from land to sea are governed to a considerable extent by the state of the forests in each watershed.

Forests perform a crucial role also in coastline protection and the quality and productivity of PNG's coastal seas and fisheries and to some extent those of its neighbours. By filtering fresh water and controlling sedimentation and erosion, Papua New Guinea's forests maintain the conditions necessary for the development of fringing coral reefs, seagrass beds, estuarine wetlands and lush mangrove forests, which provide important breeding and nursery habitats for freshwater and marine species, and protect the shoreline and land from storm and wave damage (Hunt, 2006).

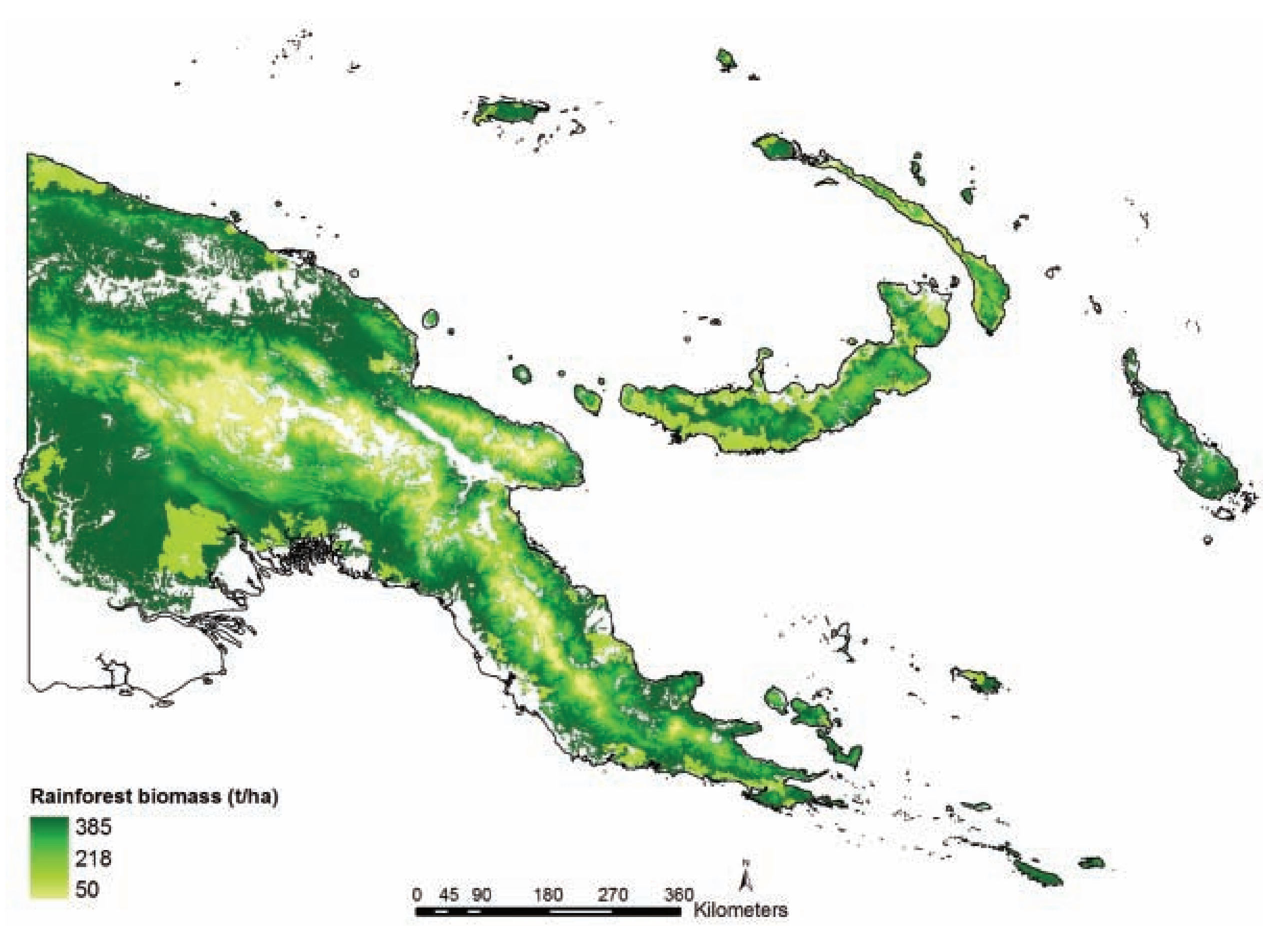
Climate stability and carbon value of PNG's forests

Tropical forests play an important role in stabilising the global climate by helping to regulate rainfall, temperature, wind and cloud regimes, and by storing enormous volumes of carbon (IPCC, 2007). It is now recognised that climate change brought about by the unregulated release of carbon into the atmosphere through human activity poses a great threat to the maintenance of the planet's biosphere. After the burning of fossil fuels, the most important sources of CO_2 and other greenhouse gas emissions are activities related to land-use change; of these, it is tropical deforestation and degradation as well as forest fires that release most carbon to the atmosphere (CIDA, 2001; Stern, 2007; Nepstad et al, 1999).

As one of the planet's greatest reservoirs of carbon, intact tropical forests are vitally important in mitigating further climate destabilisation (Lewis, 2006). However their loss through a variety of deforestation processes now accounts for 18% of annual global greenhouse gas emissions (Stern, 2007). The current global focus on the mitigation of the drivers of human-induced global warming means that the carbon stored in forests now has potential additional commercial value.

Preliminary estimates of carbon stocks in PNG have been conducted by the UPNG Remote Sensing Centre by integrating field measurements of above and below ground live biomass from across PNG, a high-resolution forest map of PNG, and bioclimatic indices. Carbon emitted through logging operations was estimated using a high-resolution 2002 forest map, a logging damage model and records of annual timber exports from logging concessions (report in preparation).

Figure 6: Estimation of biomass across PNG's extant rainforests from all published data gathered in the period 1960-2005.



The results of this assessment estimate that there were 4,724 – 4,735 million tonnes (Mt) of carbon stored in PNG's primary and secondary forests in 2002. This estimate does not include carbon stored in forest soils – a substantial carbon stock that may be reduced through loss of forest cover (Jobbagy & Jackson, 2000). Between 1972 and 2002 deforestation resulted in the release of a net 926.5 Mt of carbon (3,397 Mt of CO_2), with an additional 76.39 - 88.83 Mt of carbon (280.1 - 325.7 Mt of CO_2) being released through logging-related forest degradation.

Using the forest change model described in Annex 2, it is estimated that in 2001, 44.98 - 54.87 Mt of carbon (164.9 – 201.2 Mt of CO_2) were released through deforestation and degradation. Extrapolating the same forest change model to 2007, it was estimated that in 2007 deforestation and degradation caused the release of 63.58 – 73.25 Mt of carbon (146.5 – 268.6 Mt of CO_2). Of this total, 32% or 20.57 – 23.17 Mt of carbon (75.44 – 84.97 Mt of CO_2) occurred due to logging activities. At a nominal value of $US10 per tonne, the estimated value of this carbon loss is greater than the FOB value of log exports in 2007.

The local impacts of climate change in Papua New Guinea

Local climate change impacts in PNG are potentially very serious given the fact that the majority of the population lives in a subsistence economy which is highly vulnerable and has limited capacity to adapt to impacts (NSO, 2000). The major direct effects of global warming and sea level rise for PNG are likely to be increased humidity, coastal inundation, storm surges, salt water intrusion of coastal groundwater systems, water table elevation, changes to coastal landforms, and decrease in human comfort (Bualia and Sullivan, 1990). Already some island communities are being forced to relocate to the mainland. It is also likely that the forests, in particular those across southern New Guinea, will come under increased risk of burning, especially if these forests continue to be logged, and logged intensively.

Global warming is linked to increased severity in El Niño weather patterns and it is suggested that seasonal variability will increase, causing increased flooding, mudslides and more frequent and severe droughts (IPCC, 2007). There is concern about the spread of endemic malaria from coastal areas of PNG to the densely populated highlands. In the past, the highland populations have been protected by altitude; both insect vector and parasite have been deterred by the low temperatures on the central plateau (approximately 1,500 m above sea level) (Muller et al 2003). This barrier is being diminished with global warming: it has been estimated a doubling of effective CO_2 will raise isotherms by 300 m (McGregor, 1990). There is also uncertainty about the impacts that climate change will have on Papua New Guinea's biodiversity. A shift to novel climate regimes is likely to be disruptive since it forces ecosystems into climatic ranges outside those in which they evolved (IPCC, 2001; IPCC, 2007). Ecological zones will tend to shift upwards and displace lower and upper montane ecosystems where these occur (Beckage et al. 2008). However, this may well destroy such systems, which are already under considerable pressure from forest and grassland fires.

Spiritual and cultural values

Perhaps the least recognized but locally most significant values of the forests of Papua New Guinea are spiritual and cultural (Montagu, 2001). Each distinct community in Papua New Guinea, and there are more than eight hundred recognized local language groups, has a unique relationship with its forest and general environment. Forest lore is a vast and largely private area that cannot be easily summarized or generalized, but is of importance to many Papua New Guineans. For many groups the forest is infused with the presence of their ancestors who continue to play an important role in their daily lives. For local people it can also be home to non-human spirits, which must be respected and whose distinct domains cannot be infringed upon without risking harmful consequences.

The values of commercial timber extraction

Over the past thirty years, logging of the country's diverse rainforests has developed as the main industrial activity across many parts of Papua New Guinea. The reported annual volumes of raw log exports and their value in PNG kina are presented in Figure 7. In 2006, 2.65 million cubic metres (m^3) of unprocessed logs were exported, with a declared value of 491 million kina (US$167 million). In addition there were exports of sawn timber, veneer, plywood sheets and wood chips worth K70 million (US$22 million). The sector contributes about K100 million (US$32 million) to government revenues annually, principally through a tax on the value of logs exported. It is estimated that around 7,500 people are employed in the logging and timber processing industries nation-wide (ODI, 2006). In addition, Papua New Guinea has some 70,000 hectares of plantation forest which provide a minor contribution to the total timber harvest.

In the years after Independence, the amount of commercial logging in Papua New Guinea's forests began to increase substantially, with a particular impact on the Islands region where stocking densities of commercially valuable timber species were highest and access was relatively simple, as the forests fringed the coastline (Bun et al, 2004). Logs could be trucked to the coast and transported via barges to ships that took logs directly to overseas destinations.

In the 15 years from 1972, the volumes of log exports from PNG tripled from below 500,000 m^3 each year to 1,450,000m^3 in 1987. From 1991 to 1994 volumes more than doubled again to reach close to the 3 million m^3 mark, and stayed at these levels until the Asian Economic Crisis decimated log prices. The export volume fell back to 1.5 million m^3 in 1998, since when it has steadily increased again, reaching 2.28 million m^3 by 2005 and 2.7 million m^3 in 2006 (Gresham, 1982, PNG Forest Authority Timber Digests 1976-2005; Bank of PNG, 2006; SGS, 2005-2007).

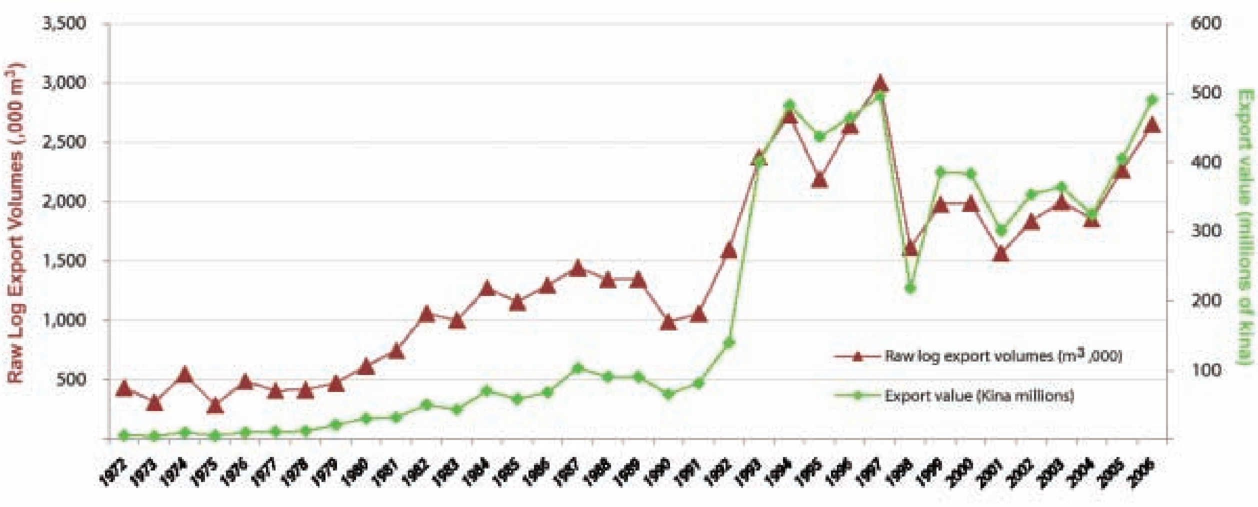


Figure 7

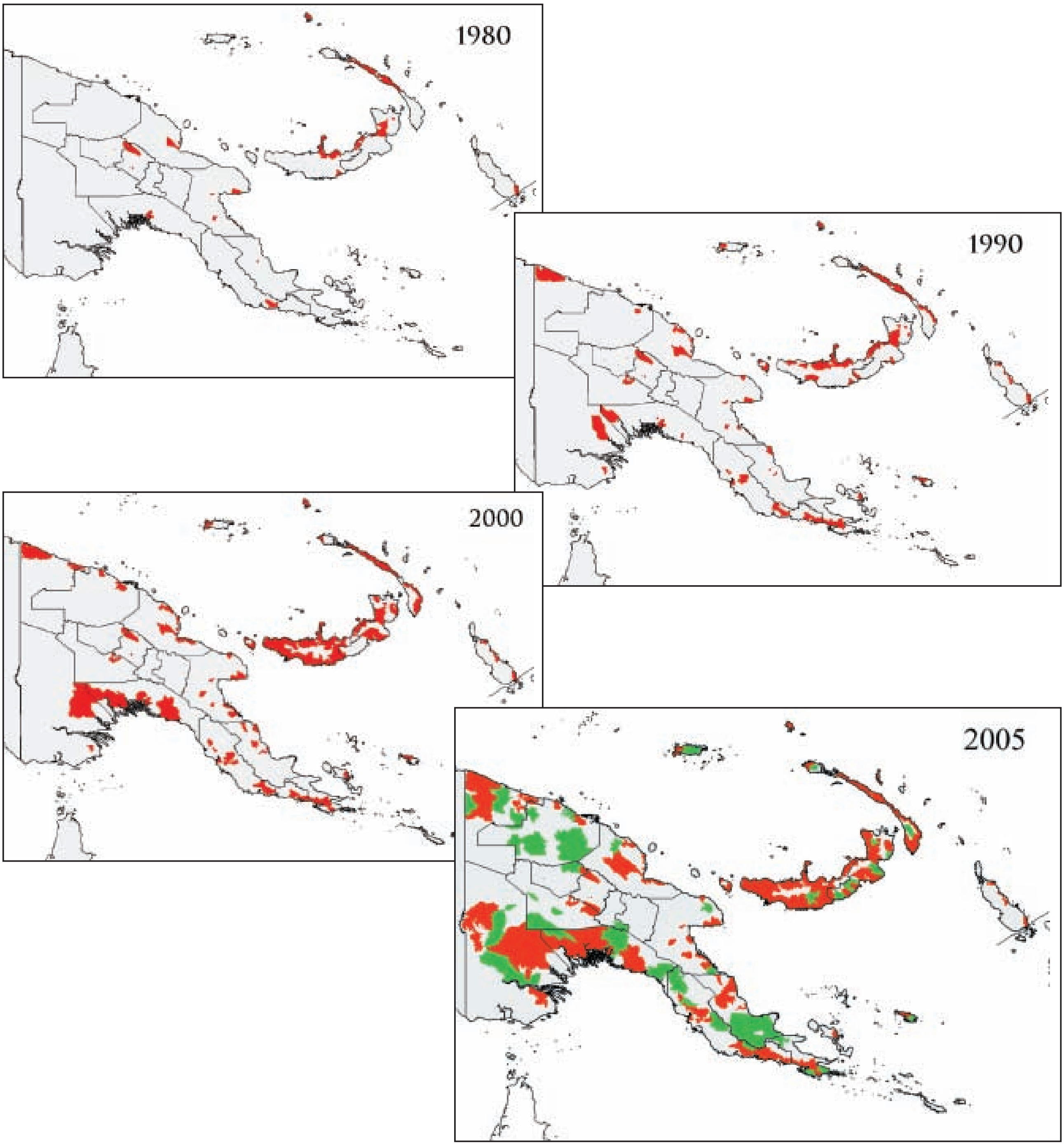
Raw log export volumes in thousands of cubic metres and value (kina) from 1972 to 2006. (1972-1977 derived data from Gresham, 1982. 1978-2006 data obtained from Bank of PNG, 2006; SGS, 2005-2007).

The level of logging increased in the 1990s with the development of new concessions on the mainland, at the same time as opportunities for new logging concessions in the Islands region were falling as the richest accessible forest areas were logged out. The mainland concessions were less economically attractive as the mainland forests contained a lower density of high-value species and access could be difficult due to complex river systems and seasonal inundation (Bun et al, 2004). This led to a demand for larger concession areas in order to exploit economies of scale.

By 2005, a total of 217 commercial logging concessions (Timber Rights Purchases, Local Forest Areas or Forest Management Agreements) had been acquired and allocated, covering 10,501,605 hectares (SGS, 2005). In January 2006, 33 of these concessions were in production, defined as having exported raw logs within the previous three months (SGS, 2006). The thirty-three active concessions covered a total area of 5.25 million hectares with the size of individual concessions ranging from 15,000 up to 1,722,000 hectares. The average concession size was 159,110 hectares. The logging sector is dominated by Malaysian-owned interests and their primary markets for raw logs are in China (80%), Japan and Korea (Bun et al, 2004). Some commercial logging also takes place outside of the concession areas.

The data from the present study indicate that over the 30 year period from 1972 to 2002, 3.8 million hectares of PNG's forests were degraded or cleared by logging operations, and the total declared value of logs exported was 4.57 billion kina, which equates to a CPI adjusted value of 2,262 kina per hectare of logged forest.

Figure 8: This time series shows the sequential allocation of forest areas to the logging industry between 1980 and 2005. Areas in red are allocated while areas in green are designated as production forests.



Changes in Papua New Guinea's Forests: 1972 to 2002

This study of the state of Papua New Guinea's forests provides high resolution data on the changes that have occurred over the past thirty years and examines the main drivers of those changes and their distribution across the country. Net forest change was assessed by comparing a '2002' land-cover map, created from high-resolution satellite imagery taken between 2000-2007, with a compatible '1972' land-cover map created from very high-resolution aerial photographs taken by the Australian Army between 1972-1975. The methods used to compile the time series of forest cover data for the country are described in Annex 2 of this report.

The 1972 baseline was chosen in order to examine change over the period since PNG became an independent nation in 1975, and because of the high resolution and accuracy of the aerial photography and mapping that had been undertaken by the Australian Army from this period. The scale of forest mapping in both the 2002 and 1972 land-cover maps allowed changes in forest boundaries exceeding 60 m to be detected and with high confidence. The analysis measured the areas of each discernible forest type that were deforested or degraded between 1972 and 2002, and then assessed the extent to which the changes were due to forest logging operations or non-forestry processes (subsistence agriculture, forest fires, plantation development or mining).

The study measured both forest degradation and deforestation across each of PNG's geographically distinct regions: the Island region, the Highlands region and the Mainland Lowland region (Figure 1). Due to the predominantly rugged terrain of PNG, much forest is inaccessible to mechanized logging and only large accessible areas can support commercially viable logging operations. For this reason, the study also measured the extent of commercially accessible forests across the country, and the rates of deforestation and degradation that had occurred in them.

Deforestation and degradation – definitions

Deforestation: The replacement of forest with other land-cover types including subsistence gardens, plantations, grassland, or scrub. Such replacement may be persistent or, after many decades, lead to re-establishment of forest by the process of succession. Subsistence agriculture, logging, fire, and land clearing for mining are all known drivers contributing to deforestation (Wunder, 2003; Haberle, 2007; Regan and Griffin, 2005; McAlpine and Freyne, 2001). Deforestation affects biological diversity in three ways – destruction of habitat; isolation of fragments of formerly contiguous habitat; and edge effects in the boundary zone between forest and deforested area. These effects include increased exposure to drying winds, risk from fire and greater access to hunters, each causing a net loss of plants and animals in the edge areas (Skole and Tucker, 1993).

Degradation: The process of conversion of primary or climax forest into secondary forest through commercial logging or low intensity burning. Degraded forest results where significant damage has been caused to the forest's structure and ecology without complete elimination of the forest cover. Degradation through commercial logging includes felling trees for timber and associated uses (ramps, roads, bridges, wharves, etc), associated damage to adjacent forest, vehicle access tracks to extract timber, haulage roads, wharves, areas cleared for log storage, and other infrastructure. The total volume of trees killed by logging operations is typically 15-16 times the volume of timber exported. In other tropical forests, logging practices similar to those in PNG have been documented to cause severe damage to forests. In Amazonia typically, 10-40% of the forest's total living biomass is killed or damaged during logging (Nepstad et al, 1999). Other impacts of commercial logging include damage to other vegetation and soils, substantial carbon emissions, and increased vulnerability to both fire and subsequent conversion to grassland, scrub, or agricultural lands. What is known about the ecology of PNG's forest suggests also that repeat logging within a short period predisposes the area to grass invasion, fire and eventual conversion to grassland. (Uhl and Vieira, 1989; Asner et al, 2005; Nepstad et al, 1999; Abe et al, 1999; Verburg and van Eijk-Bos, 2003; Holdsworth and Uhl, 1997).

Summary of 30 years of changes in PNG's forests

In 1972, Papua New Guinea had 38.0 million hectares of intact forests covering 82% of the country's total land area of 46.2 million hectares. There were approximately 33.2 million hectares of rainforest. There were in addition an estimated 3.4 million hectares of swamp forest, 0.6 million hectares of mangroves, and 0.75 million hectares of dry evergreen forest.

In 2002, there were 25.3 million hectares of intact rainforest remaining across the country, and 2.9 million hectares of secondary forest that has been degraded through logging. The other types of forest were comparatively unchanged over the intervening period.

Between 1972 and 2002, 15% of PNG's diverse rainforests had been cleared and 8.8% had been degraded to secondary forest. A total of 7.9 million hectares, 23.8% of the 1972 forest estate, had therefore been destroyed or degraded, overwhelmingly by human activity. The extent of these changes since PNG's Independence in 1975 amounts to the deforestation or degradation of nearly a quarter of the country's most valuable living natural resource, at rates much higher than previously estimated or reported.

It is clear from the study that the majority of the changes in PNG's forest cover took place in the second half of the study period. While at Independence PNG had experienced little economic development and population growth was relatively slow, the last 20 years have seen massive logging expansion, a doubling in the human population and the occurrence of a variety of other forest-clearing activities.

The analysis estimated the contribution of each of the main drivers of forest change: 48.2% of the total forest change recorded between 1972 and 2002 was due to logging; 45.6% was driven by expansion of subsistence agriculture; 4.4% was due to forest fires; 1.2% to the development of plantations, and 0.6% to the development and operation of mines.

Subsistence agriculture

The conversion of forest land to gardens for subsistence agriculture was the main driver of deforestation in PNG between 1972 and 2002. Over this period, 3.6 million hectares, 11% of the 1972 forest cover was cleared through subsistence-related activities.

Logging

Forestry operations are confirmed by the study as the main driver of overall forest change in PNG, responsible for deforestation of 0.9 million hectares and degradation of a further 2.9 million hectares of primary forest between 1972 and 2002.

Commercial logging in PNG has been heavily concentrated in forest areas that are accessible by bulldozers, trucks and coastal shipping. Across the whole country, these accessible areas totalled just 13 million hectares, 41% of the 1972 forest estate. Of critical concern is the study finding that by 2002, 36% of these accessible forest areas had been deforested or degraded.

Forests mapped in the study as accessible to mechanised logging covered 59% of the Islands region and 42% of the Mainland lowlands in 1972. By 2002, 63% of the accessible rainforest in the Islands region (1.8 million hectares out of 2.9 million hectares) were deforested or degraded, while the equivalent figure for the Mainland lowlands was 29% (2.9 million hectares deforested or degraded out of 10.1 million hectares).

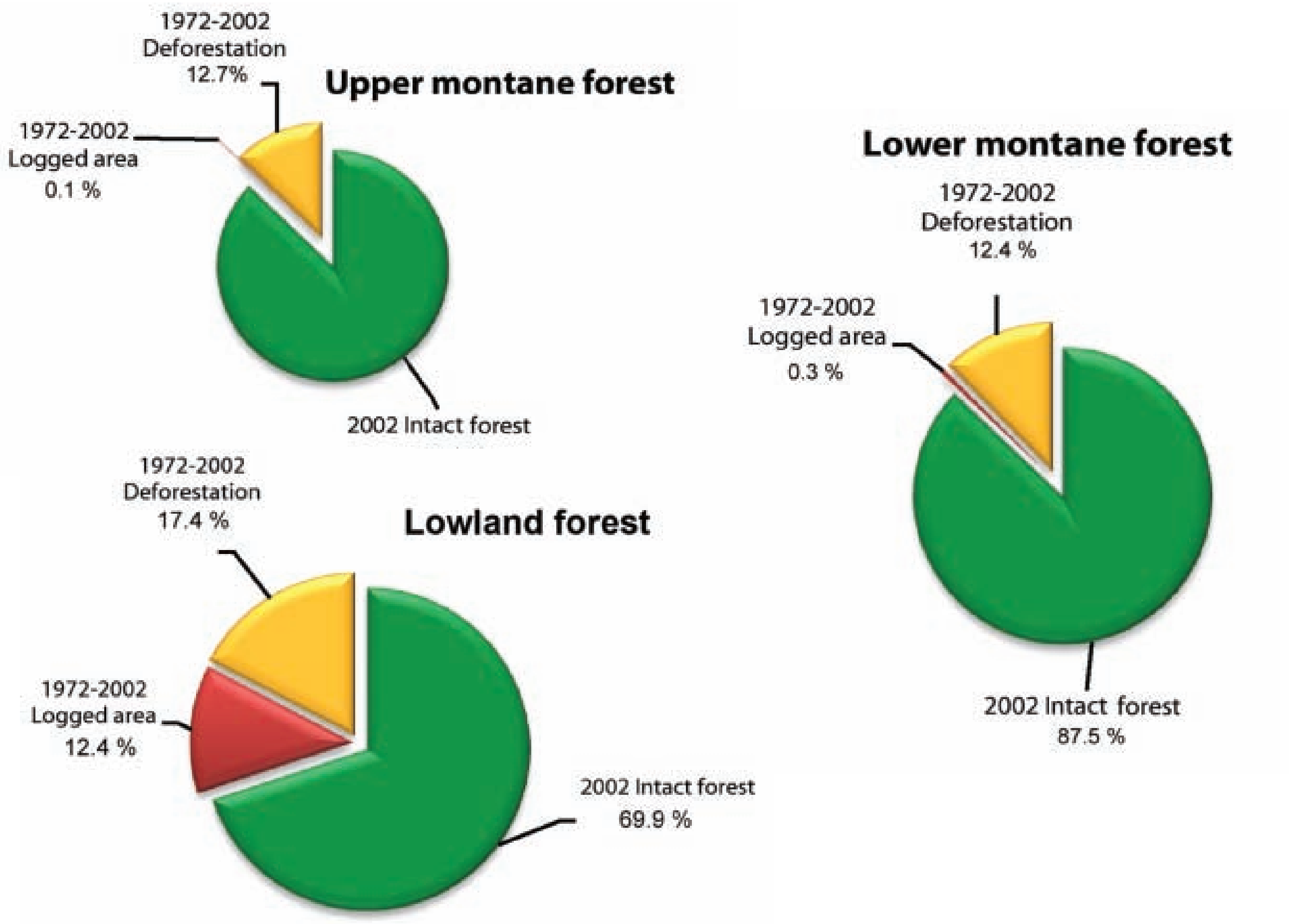
Regional variation in forest change

One of the principal findings of the analysis was that lowland rainforests have undergone a disproportionate amount of change. Of the country's total 22.7 million hectares of lowland forest in 1972, 6.8 million hectares (30.0%) were cleared or degraded by 2002. The rates and intensity were highest in the Islands region: in New Ireland, 53% of the 1972 forest area of 820,606 hectares were deforested or degraded by 2002; while across New Britain, 46% of the 3.2 million hectares of 1972 forest suffered similar change. In the same thirty year period, greater areas but lower percentages of lowland forest on the mainland were changed: there, over 5 million hectares of lowland rainforest, 21% of the 1972 cover, were deforested or degraded by 2002, ranging from 16% in East Sepik to more than 27% in Milne Bay.

These high levels of impact indicate the degree to which PNG's lowland forests have been preferentially selected for forestry and agriculture, both because they are the most accessible, and because they produce the highest timber volumes and crop yields. In addition, lowland forests growing in low rainfall zones suffered a disproportionate amount of deforestation and degradation compared to other lowland forests.

PNG's important montane forests also suffered unexpectedly large amounts of change in the study period, estimated at 13% being cleared or degraded between 1972 and 2002. A total of 1.26 million hectares of the lower montane zone and more than 101,000 ha of the upper montane zone were deforested, while a relatively small area of 53,400 hectares was degraded through logging in montane areas. The main drivers of these changes are likely to have been garden expansion and increased frequency of fire, almost certainly due to human-ignited fires. The severe El Niño drought events between 1972 and 2002, and especially in 1997-1998, led to increased human presence in the upper montane zone and increased ignition of fires. In combination with increased forest flammability, these impacts resulted in substantial deforestation in the lower and upper montane zones. These forests contain a disproportionately large percentage of PNG's biodiversity, which makes their loss particularly significant.

Figure 9: Changes in forest extent between 1972-2002.



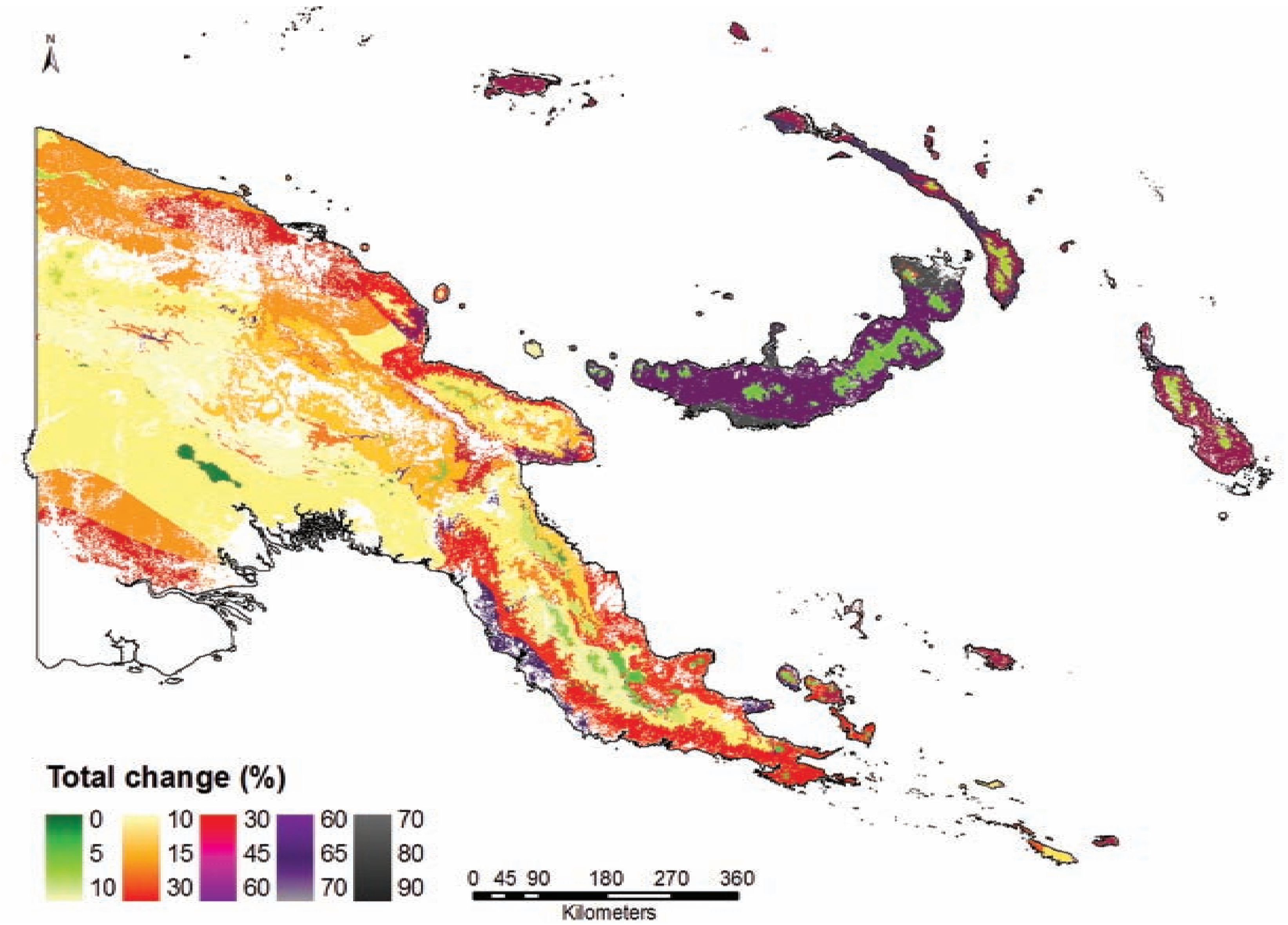


Figure 10: Change in PNG's rainforest cover between 1972 and 2002. Forest change measures the percentage of forest area in 1972 that was deforested or degraded by 2002. These data are displayed in sub-regions of PNG's 1972 rainforest cover and have been differentiated according to biogeographic regions and climatic zones.

2.2 Annual rates of forest change in PNG

The study found that clearance and degradation of tropical rainforest across PNG were extensive and rapid between 1972 and 2002. It is likely that most of this deforestation and degradation occurred in more recent years. This is because timber exports and population, associated with forestry, plantation and subsistence clearance increased substantially in the latter half of the 30-year time period (see Figures 7 and 13).

The rates of deforestation and degradation attributable to each driver were estimated for each year of the 30-year study period on the basis of the following model assumptions: that subsistence-related deforestation followed the same trajectory as human population increase; that logging-related deforestation and degradation are tracked closely by timber export volumes; that plantation-related deforestation tracked lagged oil palm exports and; that all large forest fires not associated with subsistence agriculture or logging tracked the occurrence and intensity of El Niño years. The results are presented in Figure 11. It is important to note that these models are simply allocating known sources of change to particular years and have no influence on the total change or its cause.

It is apparent from these estimates that the of rates of forest change in PNG have increased considerably, from an overall loss of 0.44% of forest cover per year in the early 1970s, rising to 1.76% per annum in the period 1997-1999 when the dual influences of high rates of logging and the El Niño-related fires destroyed and degraded large areas of forest. The model suggests that change rates remained relatively low at around 0.4% per year prior to 1980, but that the rate increased steadily from the 1980s onwards as both logging activity accelerated and the human population and demand for food grew. By the end of the analysis period, around 2002, there was a combined rate of forest loss of 1.41%, comprising deforestation of 0.77% and degradation of 0.64% of forest area each year. Statistics regarding the relative proportion of change estimated to have been caused by each of the drivers of change in each province are presented in Annex 1.

The rates of forest change estimated by this analysis from 1980 onwards are considerably higher than all previous estimates of forest change in PNG, including those reported by the FAO (2000, 2005b). The reasons for the apparent under-estimation of deforestation and degradation are discussed in Annex 3. It is clear that rapid and substantial forest change has occurred in PNG, and that the major drivers are logging in lowland forests and subsistence agriculture in the Highlands, with minor contributions from forest fires, plantation establishment and mining. Furthermore, these rates are almost certainly under-estimates of the rates of change since 2002, due to recent escalation of logging activity and further population growth. Extrapolation of the impacts of continued population growth and logging activity over the period 2002-2006 suggests that rates of deforestation and degradation increased to approximately 0.89% and 0.82% respectively, giving a total change rate of 1.71% of forest cover per year in the 2005-2006 period.

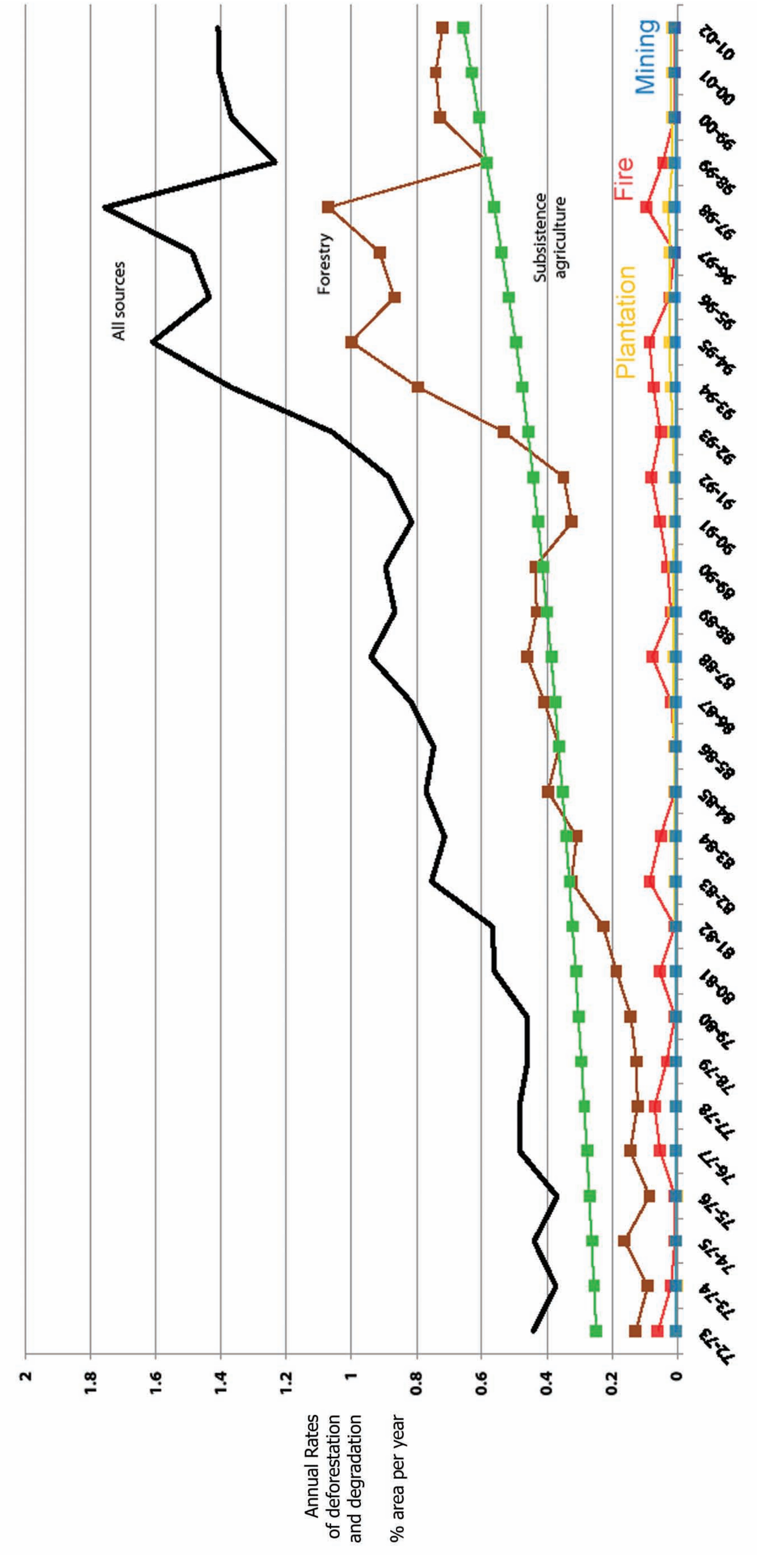


Figure 11: Estimation of annual rates of forest change (%/yr) for each of the identified drivers of change over the period 1972 - 2002.

2.3 Rates of change in forests accessible to logging

The rates of change in forest cover were also measured specifically for areas where the forest is potentially accessible to commercial mechanized logging. The analysis estimated that, based on the terrain and location, 13.5 million hectares (41%) of PNG's 1972 rainforest areas were accessible for this purpose. It is estimated that in the thirty years from 1972 to 2002, 4.8 million hectares or 36% of this accessible forest was deforested or degraded. In the Islands region, where commercial logging was focused first because of relative ease of access and the high density of the forest, the major part (63%) of the accessible forest, over 1.8 million hectares, had been deforested or degraded by 2002.

The analysis estimates that nationally by 2002, the annual rate of deforestation in commercially accessible forest areas was 0.78% and the rate of degradation was 1.84%, amounting to a combined loss of 2.62% of accessible forest area per year, nearly double the rate calculated for PNG's forests as a whole. Extrapolation of the impacts of continued population growth and logging activity over the period 2002-2006 suggests that within accessible forests the rates of deforestation and degradation increased to approximately 2.50% and 0.93% respectively, giving a total change rate of 3.43% in the 2005-2006 period. This focus on changes in PNG's commercially accessible forests rather than in all forests, makes it clear how quickly the country's timber resources are being depleted. Recognising the seriousness of these rates of forest loss is an important first step towards introducing effective management of PNG's forestry sector.

The assessment of accessible forest area and change for each province is detailed in Annex 1. Table 5 summarises the data for PNG and changes in the areas of primary rainforest and primary rainforest accessible to commercial logging between 1972 and 2002, due to both deforestation and degradation. Table 6 compares the rates of forest change in PNG with comparable estimates that have been made for forests in the Brazilian Amazon (Asner et al, 2005; INPE, 2007). This strongly suggests that PNG's forests are experiencing rates of change similar to those in other forested tropical regions.

Table 5: Area of primary rainforest and primary rainforest accessible to commercial logging in PNG in 1972 and 2002, and change (%) due to both deforestation and degradation over this period. Swamp forest, mangrove and dry evergreen forest are excluded. DF refers to the proportion of 1972 forest area deforested by 2002, DG refers to the area degraded, Tot. refers to the area deforested and degraded.

Region	All rainforest					Accessible rainforest				
	1972 (ha) Primary	2002 (ha) Primary	Change (%)			1972 (ha) Primary	2002 (ha) Primary	Change (%)		
			DF	DG	Tot.			DF	DG	Tot.
Islands	4,885,727	2,699,103	21	24	45	2,877,354	1,064,717	22	41	63
Highlands	4,776,533	4,104,916	14	0	14	507,092	436,716	11	3	14
Lowland coastal	23,565,330	18,528,234	14	7	21	10,090,542	7,182,347	12	17	29
Total	33,227,590	25,332,253	15	9	24	13,474,988	8,683,780	14	22	36

Table 6: Rates of forest change rates in Papua New Guinea compared to the Brazilian Amazon.

Region	2001-2002 change rates (% area per year)		
	Deforested	Degraded	Total
Papua New Guinea			
All forests	0.77	0.64	1.41
Accessible forests	0.78	1.84	2.62
Brazilian Amazon*	0.58	0.34	0.92

** Derived by dividing the 2001-2002 deforestation and degradation rates reported in Asner et al (2005) by the area of forest (3,462,811km²) in the Brazilian Amazon in 2001 reported by the Brazilian National Institute for Space Research (INPE, 2007).*

Plate 1: Lowland rainforest in the Middle Ramu area of Madang Province. Note the almost complete canopy cover.

Plate 2: Lower montane forest (1,200 m) in the Kikori Region of Gulf Province. *Araucaria cunninghamii* (Hoop Pine) is present on the ridgelines.

Plate 3: Upper montane forest - or 'mossy forest' in the Star Mountains at 3,100 m.

Plate 4: Logging in lowland rainforest in New Britain. Much of the canopy has been removed. Many of the residual trees are likely to die. Secondary forest in this degraded condition is highly susceptible to catastrophic burning.

Plate 5: Logging in *Nothofagus* forests on Mt Giluwe. Note the extensive utilisation of felled trees in the 'cording' of the roads due to very muddy terrain. A person is visible in the middle of the road.

Plate 6: Unused roads are quickly smothered in vines. These vines (*Merremia* sp.) can also be seen smothering residual trees flanking the road.

Plate 7: Large numbers of trees are used in the building of temporary bridges. Here approximately 250 trees are in the construction of this bridge in central Wawoi Guavi, Western Province. In this concession, several bridges of this size are constructed within each kilometre of roading.

Plate 8: Subsistence agriculture often requires the clearance of primary rainforest to make way for gardens. Here a recently converted garden plot in the Southern Highlands shows remnant forest trees probably killed by burning associated with the garden clearance – note the charred bases of many of the dead residuals.

Plate 9: At higher population densities much of the available land enters some form of semi-permanent agricultural use. In this valley in the Southern Highlands the entire valley bottom is covered with gardens and settlements, punctuated with copses of *Casuarina*. On the surrounding hill-slopes the majority of forest has been cleared through a combination of fire and agricultural use. Some remaining, but degraded forest is visible on the skyline.

Plate 10: Burning herbaceous swamp grassland at a lake perimeter in the lower Sepik floodplain, East Sepik Province. While such human-ignited fires usually do not enter the swamp forest (visible in the lower right corner of the image), in dry times, fires can penetrate into these wooded areas.

Plate 11: Human-ignited fires in the kunai grasslands of the Strickland Gorge are common phenomena. The majority of such fires do not enter the forest, but they do on occasions and this periodicity has been sufficient to push back forest edges in many places during the study period.

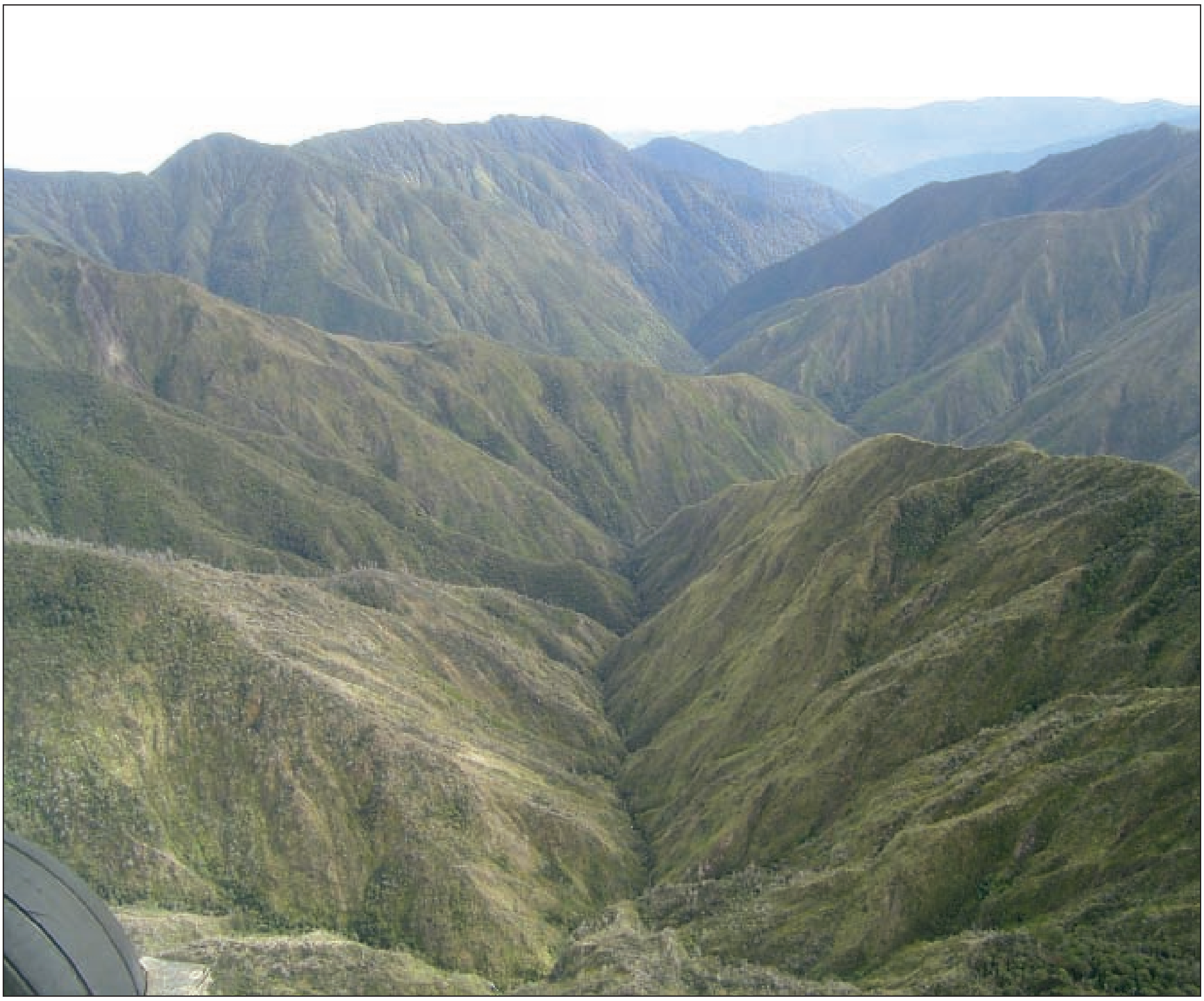


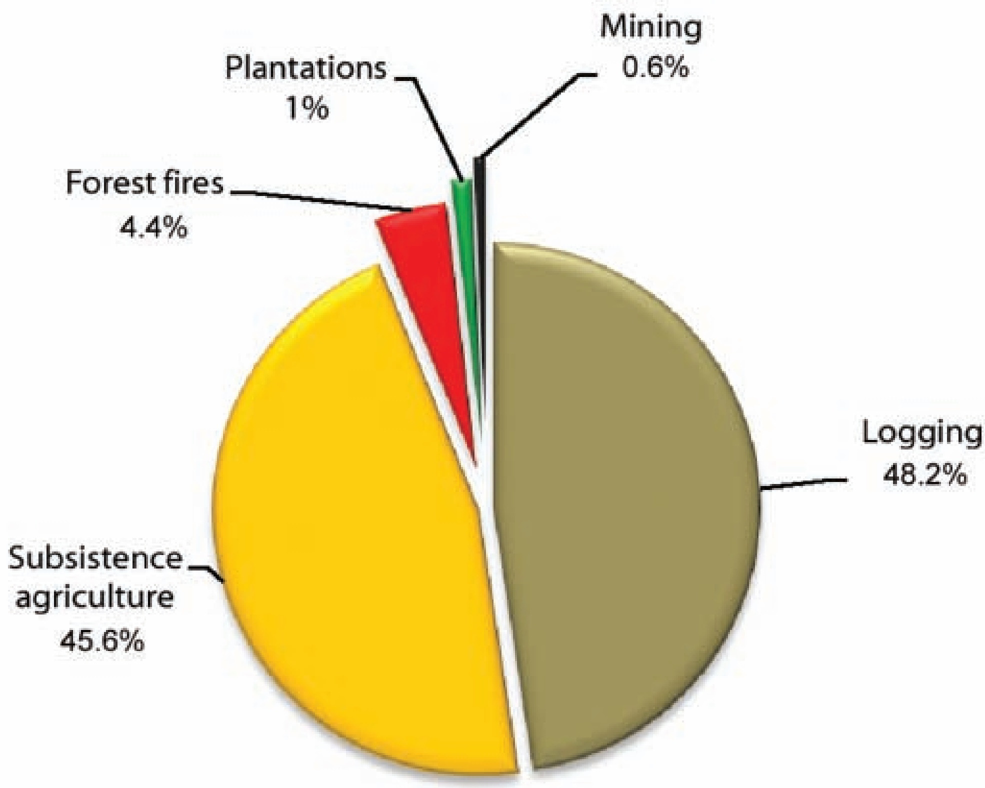
Plate 12: The upper Nankin catchment in the Finisterre Ranges (3,400 m). This area was almost entirely forested as recently as 1995. Fires, probably during the 1997-1998 El Niño period deforested a large area in this mountain range. Some remnant forest can be seen in the wetter gulleys. Dead trees can be seen on some of the ridgelines and foreground.

Chapter 3

The Drivers of Forest Change in PNG

Over the past thirty years, the major causes of deforestation and forest degradation in PNG have been logging (48.2% of net forest change) and subsistence agriculture (45.6% of net forest change), with lesser causes being fires (4.4%), plantations (1.2%) and mining (0.6%). These forces have impacted upon different types of forest in different parts of the country at different rates. This section examines each of the major drivers of forest change and their relative importance across the regions of PNG.

Figure 12: The relative importance of the drivers of forest change between 1972-2002.



3.1 Subsistence agriculture as a main driver of deforestation

Papua New Guinean society is predominantly rural with approximately 80% of the population dependent on subsistence agriculture for food. A swidden system of shifting cultivation has been practised for at least 5,000 years (and perhaps 10,000 years), in which patches of forest are cleared for gardens, cultivated for a few crop cycles and then abandoned as fallows in which the regenerating forest restores soil fertility. The present analysis found that expansion of subsistence agriculture was the major driver of deforestation between 1972 and 2002, accounting for 45.6% of the net forest change recorded across the country. An estimated 3.6 million hectares, 11% of the area of intact forest in 1972, had been cleared as a result of garden expansion or subsistence-related activity by 2002.

The definitive feature of shifting cultivation is the alternation of long periods of fallow (typically several decades) with short periods of cropping (typically 2-5 years). Old gardens are left to regenerate in favour of newly cleared sites due to the deterioration of nutrient levels and the physical condition of soil, increase in erosion, multiplication of weeds, pests and diseases and disintegration of old fences (Clarke, 1976). Near villages, forests are often almost completely cleared and replaced with a mosaic of garden plots and secondary growth. Primary forest is often cleared for new gardens by people living in temporary shelters often at great distance from their villages.

Once abandoned, gardens are quickly overgrown by a herbaceous community of weeds, grasses and creepers (Paijmans, 1976). This is superseded by fast-growing, light-demanding woody plants, particularly some euphorbs, gingers, ferns, plantains and bamboos. The composition of young regrowth differs from place to place. Fast-growing but short-lived trees are gradually replaced by longer-lived trees from adjacent primary forest. The process of regeneration and succession from a garden to a secondary forest may take decades, whereas the transition to a primary forest composition may take centuries.

Shifting cultivation has nibbled at New Guinea's forests for thousands of years. At very low population densities, gardens remain isolated and revert to forest after cultivation ceases (Marsden et al, 2006). Swidden systems in tropical regions have been shown to actually enhance biological diversity by maintaining significant portions of forest at differing stages of succession (Sekhran and Miller, 1994). This does not hold true however at higher population densities, when increased demand for food leads to reduced fallow cycles and garden areas being expanded and becoming connected, which facilitates the spread of fire. Above a critical population density, there is no fallow or forest regeneration and the land is permanently in some form of agricultural use.

PNG's population grew more than exponentially between 1972 and 2002, from approximately 2.7 million to 5.6 million (Figure 13), increasing the demand for food and for saleable produce from gardens. This has been observed to lead to shortening of the swidden cycle (Allen, 1985), which in turn results in the clearance of primary forest and in some cases to the unintended conversion of secondary forests into grassland disclimax communities. Population densities in PNG varies greatly with altitude, with the highest rural population densities occurring in the Highlands region at elevations between 1,200 m and 2,500 m, as shown in Figure 14.

Several examples of forest loss associated with subsistence use are presented in Figures 16-18.

Figure 13: Estimates of PNG population (in thousands) over the period 1961-2003. (FAOSTSAT, 2005).

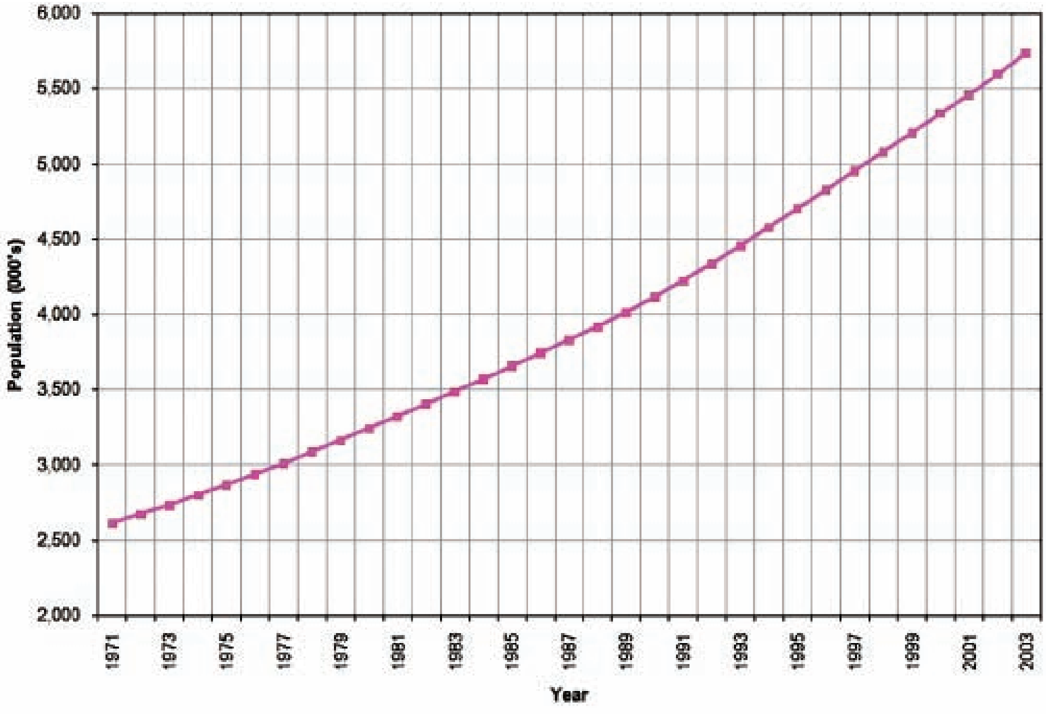
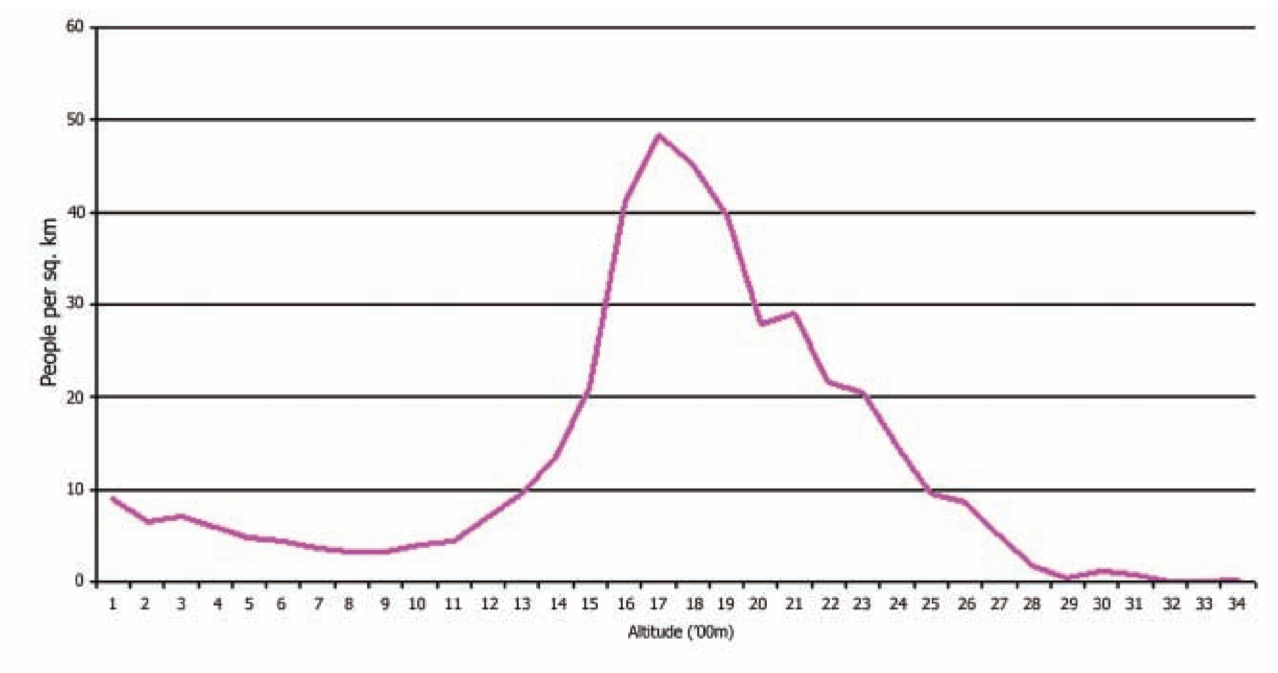
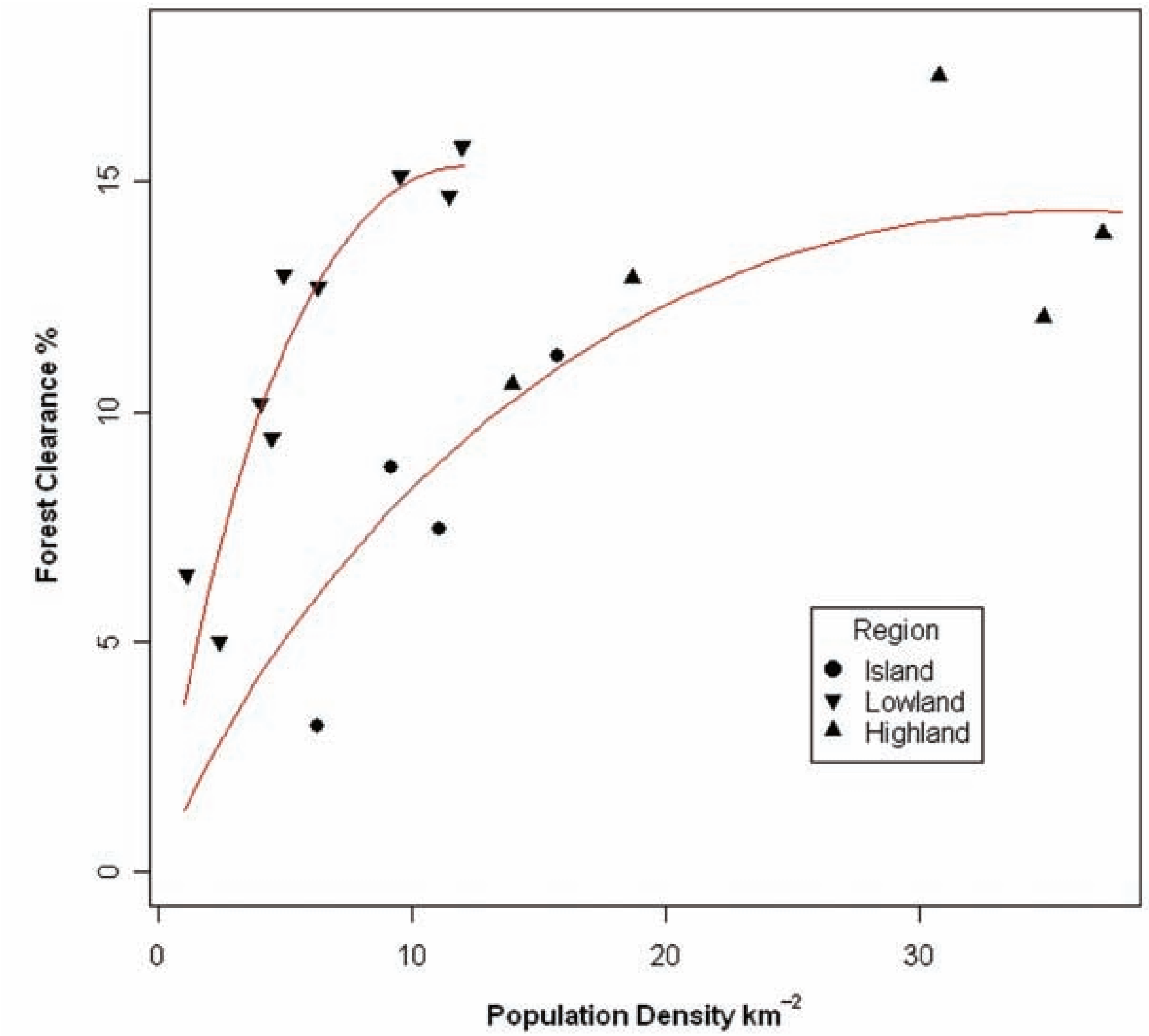


Figure 14: Population density by altitude derived from the 2000 Census figures (NSO, 2000) and a Digital Elevation model of PNG.



After adjusting for regional effects, a curvilinear relationship was found between forest clearance and provincial population density (Figure 15) suggesting that both clearance and agricultural intensification or gardening within non-forest areas increased with population density. A previous analysis of change to PNG's forests between 1975 and 1996 (FIMS) concluded that intensification rather than expansion of gardens into forest areas was the key process by which population growth had been sustained (McAlpine and Freyne, 2001; McAlpine and Quigley, 1998). The discrepancy with this study is apparently due to the lower spatial resolution of the McAlpine and Quigley (1998) study which did not delineate numerous small areas of deforestation that result from subsistence gardening as well as several other factors discussed in Annex 3. The higher resolution and longer-term analysis of the current study showed that local clearance of forest for agriculture was the major cause of net forest loss between 1972 and 2002.

Figure 15: Proportion of forest cleared due to subsistence agriculture in relation to population density in each province. The trend lines are polynomials (of order 1.25) with separate coefficients for the Lowlands and other regions combined (R^2 0.98, F 20, $p<0.0001$).



Papua New Guinea's population pressures

The population of PNG has been growing at an accelerating rate over recent decades and growth reached about 3% per year by 2000. By 2006, the estimated population was 6,248,000, growing at 3.2% per year, and showing little prospect of slowing. By 2020, the population is expected to reach just under 9 million people (NSO, 2000).

Over one third of the population is concentrated in the Highlands region, occupying just 13.5% of the country's total land area. The average density in the Highlands region is 22 persons/km^2, but in some Highland valleys has been reported to exceed 200 persons/km^2 (Allen, 2001). The next most densely populated region is the Islands (10 persons/km^2), while the southern and north-western coastal regions of the mainland have low population densities (4 and 7 persons/km^2, respectively). Western, Gulf and Sepik Provinces remain sparsely populated (NSO, 2000).

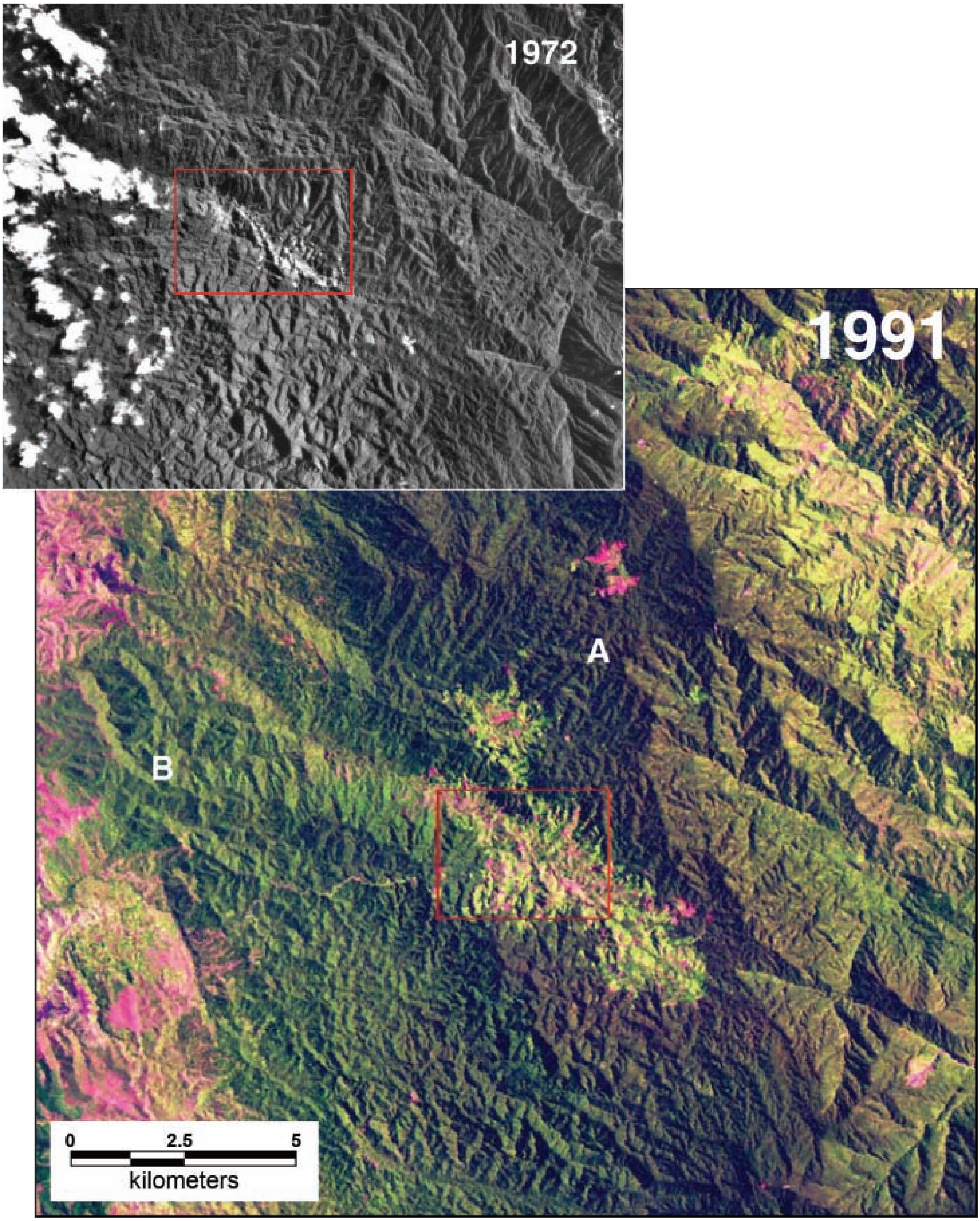
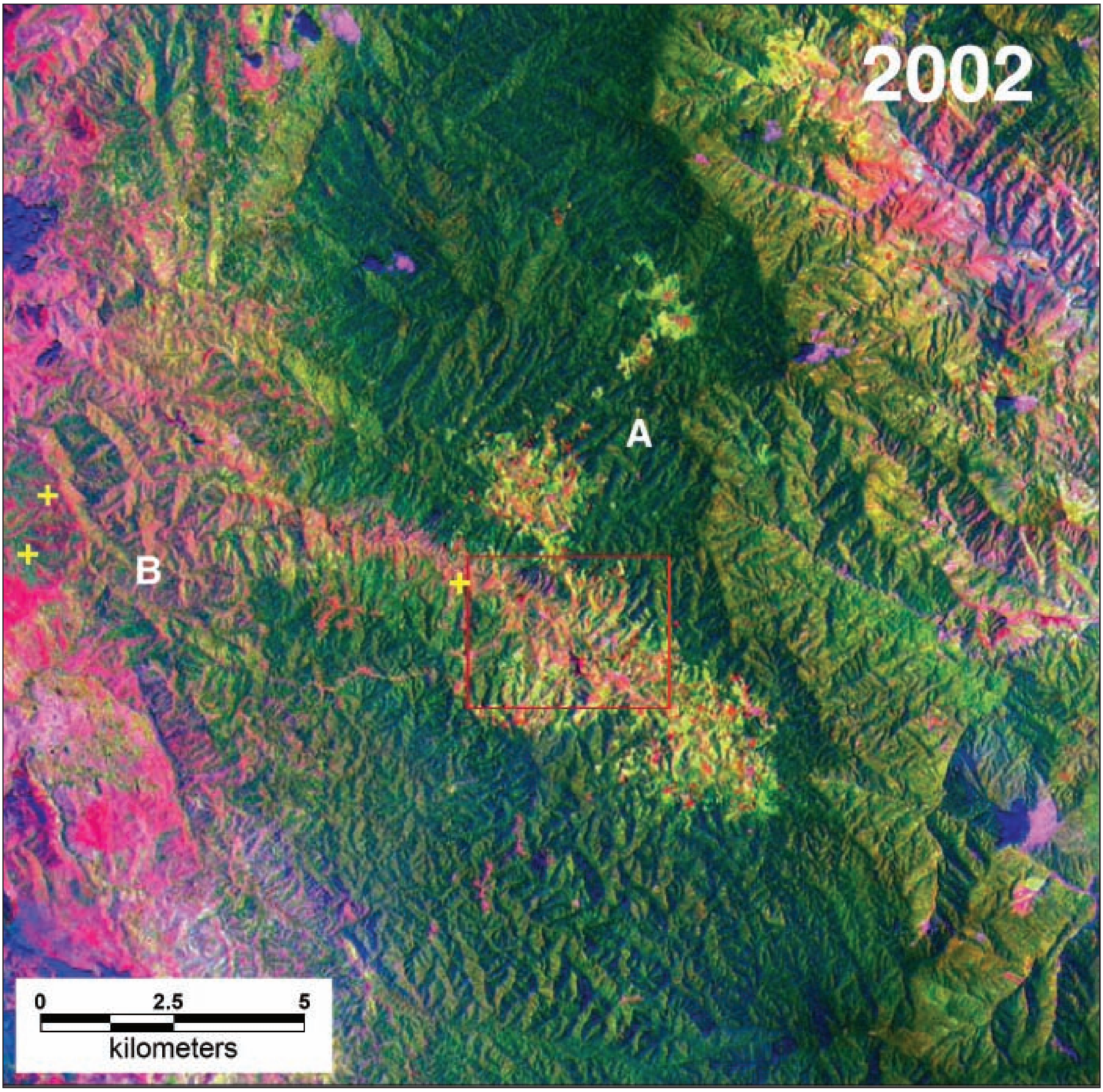


Figure 16: A time series showing a typical example of the expansion of subsistence agriculture. The zone demarcated by the red box in all three images is centred on the village of Bani, some 12 km north-east of Bulolo, Morobe Province (1,700 m altitude). In the 2000 census, 693 people were recorded in this valley. If population growth occurred here at the same rate as the whole of PNG, and if there had been no net migration, one would expect a population in 1972 of approximately 200 people.



In the 1972 aerial photo, subsistence clearance is restricted to scattered clearings in the valley bottom within the red box. Clouds are present on the left of the image. By 1991, a road has connected the area to Bulolo and the cleared area has expanded several kilometres to the east and north. In 2002 additional clearance can be seen around the margins of previously cleared areas. This is especially visible in the proximity of Location **A**. Gardens in this area could be supplying the markets of Bulolo.

Substantial forest loss and degradation can be seen in the vicinity of Location **B**, where it is likely that fires occurring the 1991-2002 interval entered forested areas and expanded the area of grassland. Hotspots from fires recorded in 2004 are shown with the symbol: +

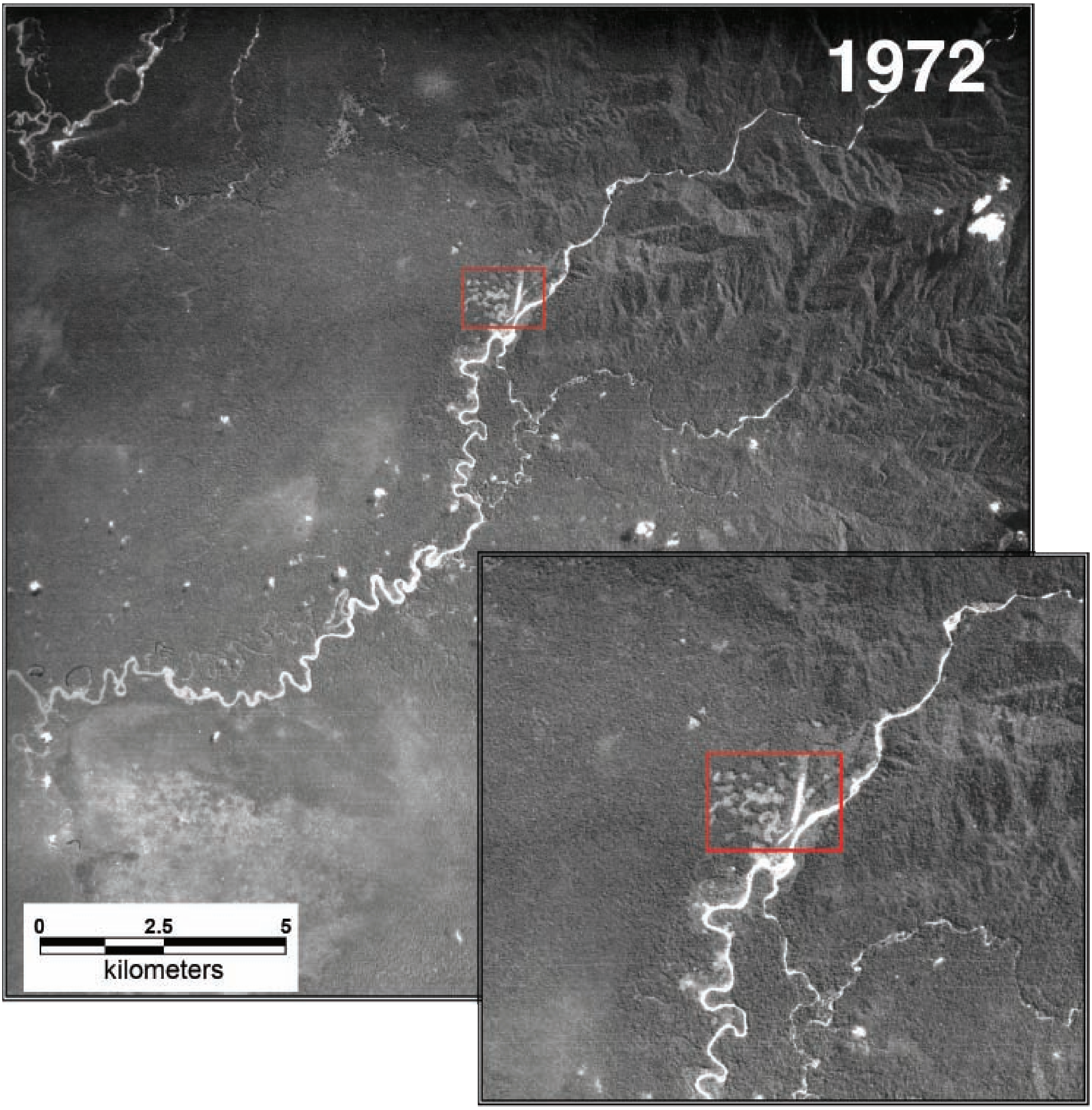
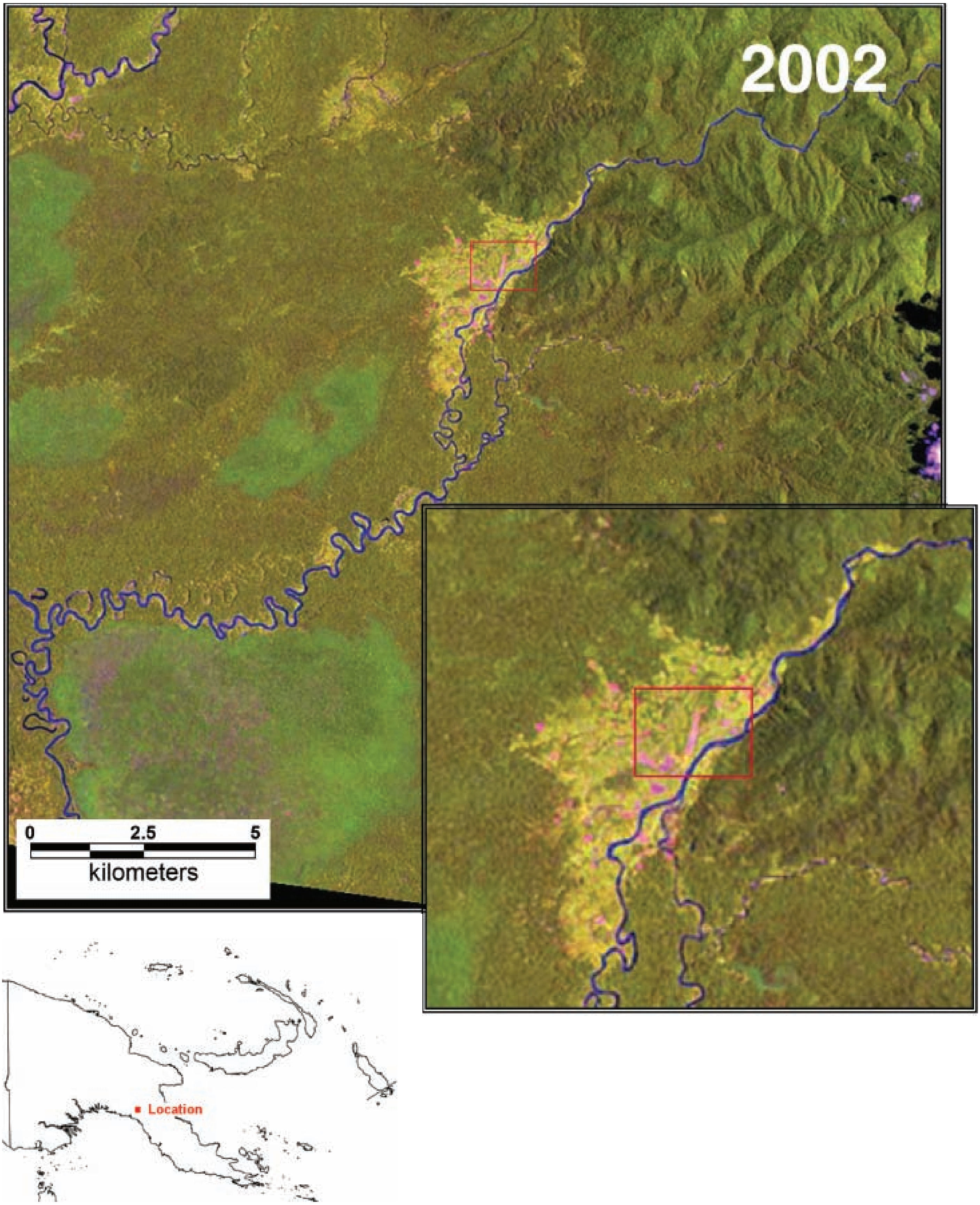


Figure 17: These images are located in the Lakekamu Basin of Gulf Province. The village of Kakoro (146° 31' 56.7"E; 7° 50' 9.8"S) and the Kakoro airstrip (180 m altitude) are visible in the red box in the 1972 (Skaipiksa) and 2002 (Landsat ETM+) images. The inserts show the area around Kakoro at a finer resolution. Substantial areas of forest clearance are visible to the west and south of the red box – in the order of 1-1.5 km expansion. A similar pattern showing expansion of subsistence agricultural activity is apparent in most areas of Papua New Guinea.


2002
0
2.5
5
kilometers
Location

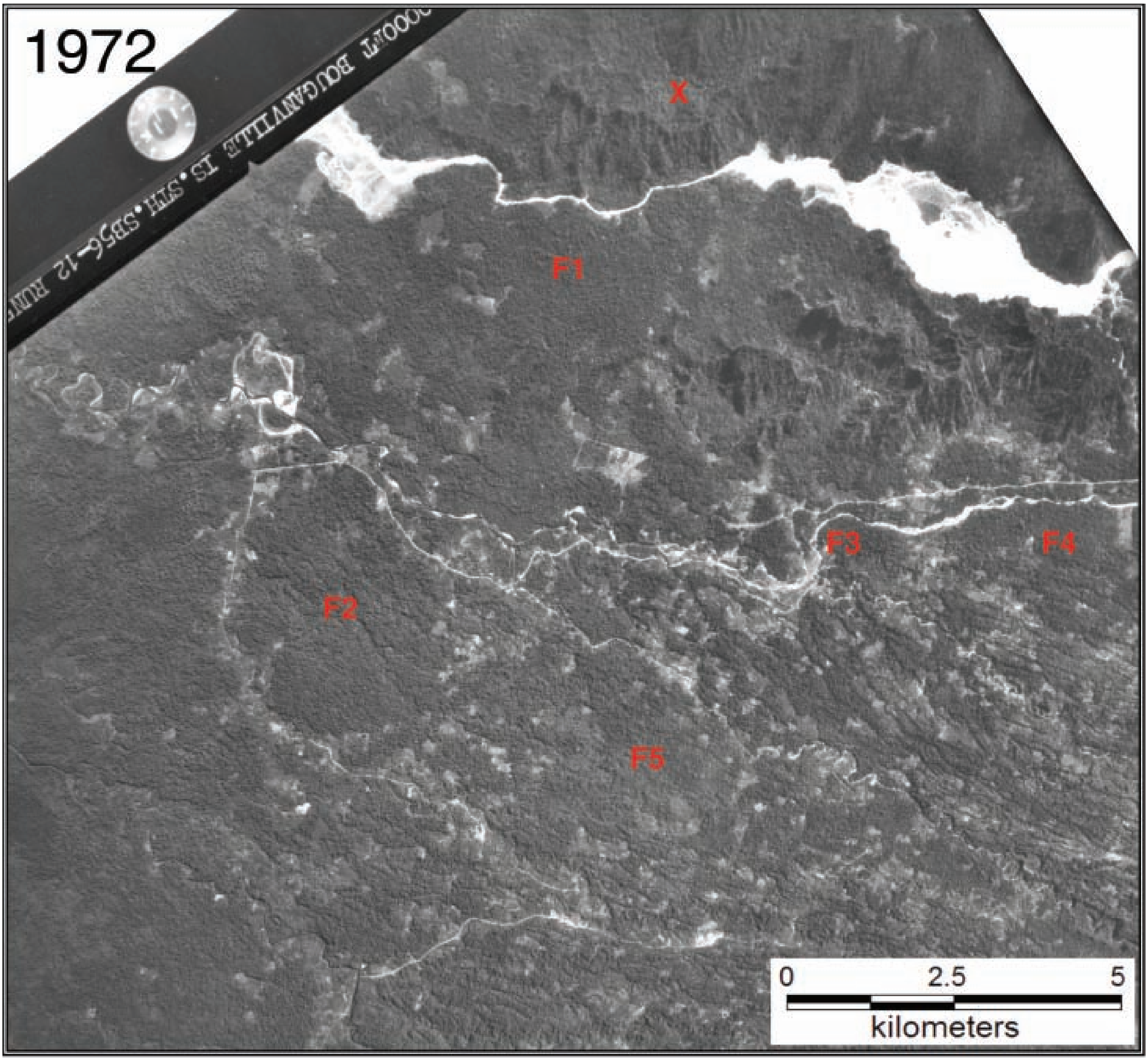
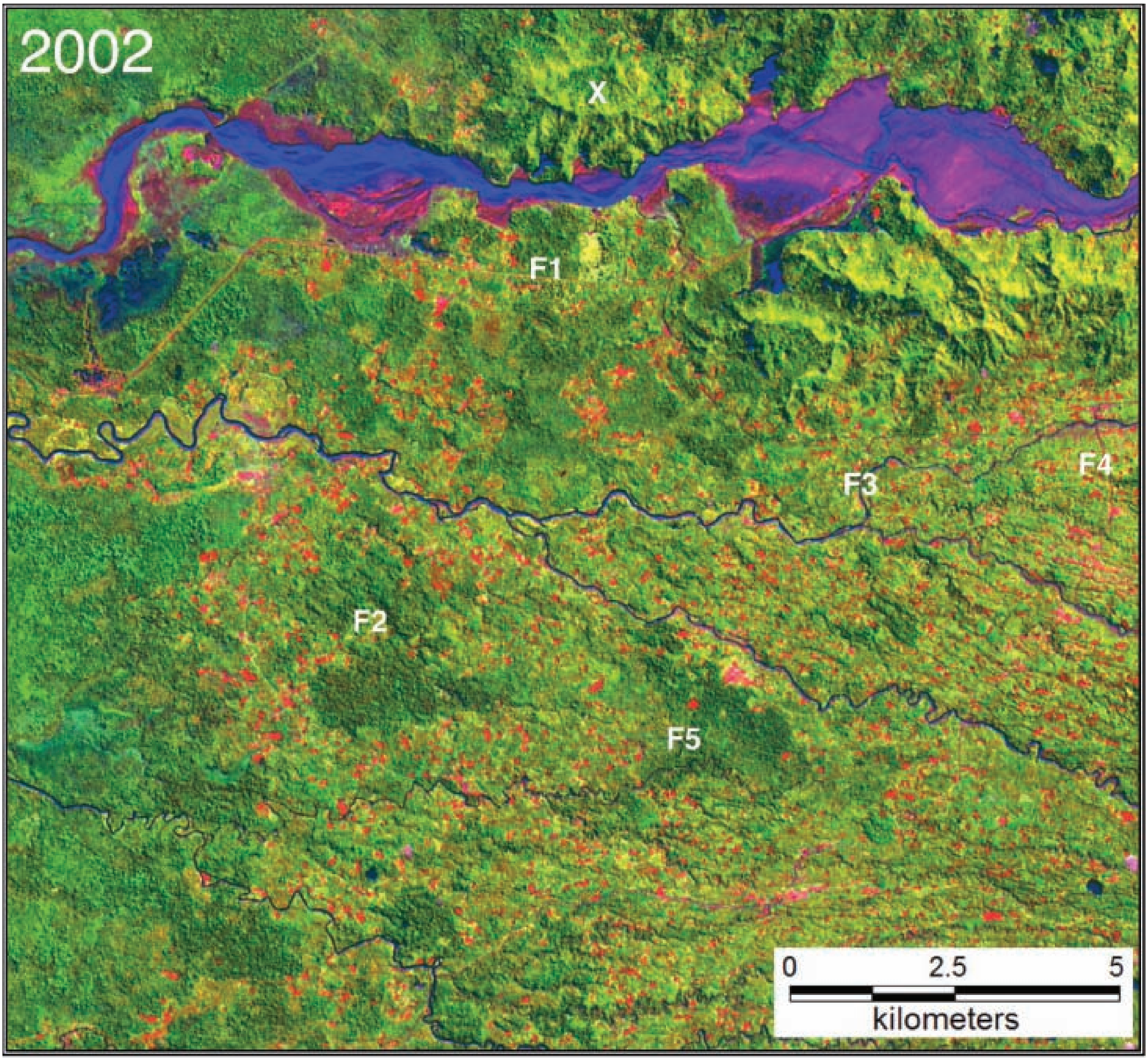


Figure 18: Expansion of subsistence agriculture in the lower Jaba River area of Southern Bougainville.

Above: A SkaiPiksa from 1972 of the Jaba River region. Areas of intact forest are visible but are surrounded by a mosaic of gardening activity.

On the right, the same area from a 2002 Landsat ETM+ image. The numbered labels present on the 1972 image are also present on this image in the same locations.

Note that the extent of forest cover surrounding **F1**, **F2** and **F5** has been dramatically reduced. Forest present at **F3** and **F4** in 1972 has been completely cleared by 2002. A large number of new gardens are visible around the location marked with the symbol **X** on both images. A similar pattern of deforestation from human activity has occurred across much of lowland Bougainville, in which fragments of forest are reduced in size, then cleared completely.


2002
X
F1
F2
F3
F4
F5
0
2.5
5
kilometers


Location

3.2 Logging as the major driver of forest change in Papua New Guinea

The forestry industry in Papua New Guinea is based overwhelmingly on the mechanised extraction of unprocessed logs for export, harvesting natural forest areas, principally old-growth stands where trees are usually hundreds of years old. There is very little timber milling or manufacturing of local timber products in PNG. There are only one wood-chipping mill, one veneer plant, one plywood factory and several commercial sawmills in the country (Forest Trends, 2006). Commercial logging and its control are highly relevant to the status and future of Papua New Guinea's lowland and middle elevation forests, and are certainly the most controversial issues regarding land-use in the country.

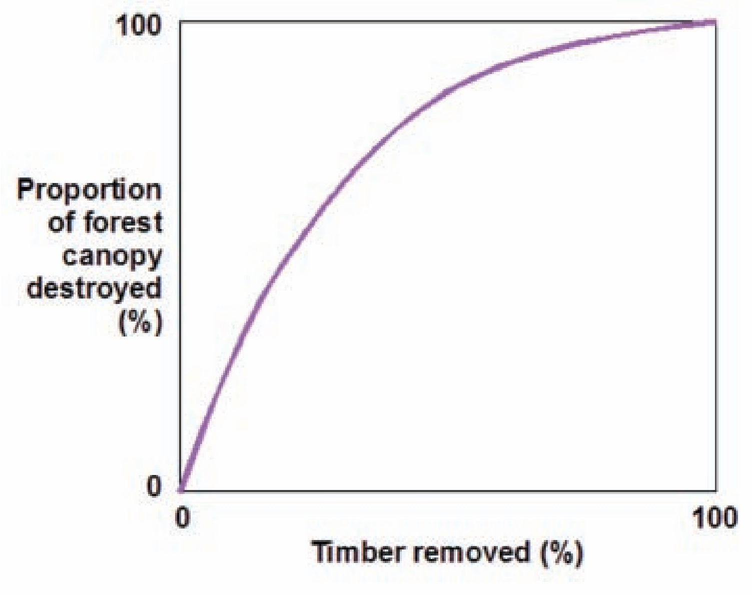
The present study found that logging has resulted in deforestation of approximately 0.9 million hectares of PNG's forests and degradation of a further 2.9 million hectares, over the 30-year period. This amounts to the clearance or degradation of 11.5% of the country's 1972 forest estate, and 48.2% of the country's net forest change.

Environmental impacts of logging in PNG

Typical logging operations in PNG involve selection and felling of trees on the basis of species and diameter (legally >50cm diameter at breast height (dbh)/above buttress), cutting the bole into suitable lengths and dragging the raw logs to logging trucks and barge transport. The logging operation itself causes substantial destruction to the forest in the form of roading and collateral damage from tree felling. A study detailing the effects of a typical logging operation found that 40% of forest tree volume was killed and that only a small proportion of this volume was extracted as logs (Abe et al, 1999). When a tree is felled, an area of surrounding vegetation is damaged up to the height of the tree and the width of its canopy. Each logged tree is dragged by bulldozer along a snig track of cleared vegetation up to 4 m wide (UPNG, 2006), to a cleared log dump accessible to trucks. Snig tracks extend up to a few hundred metres away from a log dump and road. Roads that can be used by logging trucks require a graded bulldozed track with a 5-6 m wide roadway; typically a swathe of 10-30 m width is damaged when obstructing trees are felled or bulldozed into surrounding forest. Depending on the terrain and timber volume there are 1-2km of roading per square kilometre of logged forest. A further 5% of large trees (relative to the volume of logs exported) are typically used to build bridges and ramps for the logging operation.

The practice of most logging operations in PNG over the past few decades can be described as 'selective removal of all saleable trees'. The first logging event leaves trees of smaller size or lesser value, which may then be targeted for 'salvage logging', the term used to describe the removal of inferior trees, or after a few decades, of trees that escaped removal in the first logging event and have grown sufficiently to be worth extracting. Salvage logging further degrades the remaining forest and regrowth tends to be recruitment from the successional species established after the first round of logging. Even the first time an area is logged, the selective logging practised in PNG poses a major threat by opening the canopy, increasing fuel, drying the forest and allowing fires to enter the forest (Woods, 1989; Alder, 1998). From an ecological or silvicultural perspective there is a non-linear relationship between timber extraction and forest degradation: even at low levels of log extraction, there is a marked increase in fire risk to the degraded forest canopy; while at moderate levels of extraction there is intensive degradation (Asner et al, 2005). This relationship is depicted in Figure 19.

Figure 19: A hypothetical relationship between the area degraded by varying intensities of selective logging.



Typically, the collateral damage and roading impacts are even greater than the impacts of tree removal. Gap formation and loss of a closed canopy can cause rapid drying of the vegetation, making it more prone to wildfire (Cochrane, 2003). Logged forests are especially vulnerable to the invasion of weeds such as *Merremia* sp. (see Plate 6), *Piper aduncum* and *Chromolaena odorata*, that can inhibit regeneration. It is also likely that logged areas are more susceptible to high winds and to landslides as a consequence of changes in soil hydrology. Shade-dependent understorey species are adversely impacted by the removal of the canopy. Epiphytes and animals that live in hollows in large old trees suffer major losses of habitat following logging. The impacts of logging on the flora and fauna are clearly adverse and long-lasting.

Most logging operations result in a substantial alteration in the forest composition and structure (Johns, 1992) and the categorisation of logged forest as 'degraded' is an appropriate classification. Regrowth forest has a greater proportion of fast-growing, short-lived, low-density, non-commercial species (Arentz et al, 1989). Fast-growing species that might have been restricted to forest edges and gaps (river banks, landslides or tree fall gaps) tend to proliferate at the expense of slow-growing species.

The ecological effects of selective logging on PNG's rainforest community are largely unquantified and poorly documented. There have been no in-depth, long-term studies of the state of forests before and after logging to assess whether the biota will recover to its prior composition. In other tropical regions, logging practices similar to those in PNG, where the forest is degraded but not cleared completely, have been documented to cause severe damage to the forest habitats and ecology. In Amazonia, 10-40% of living forest biomass is typically killed during logging (Asner et al, 2005). Other impacts include damage to soils, substantial carbon emissions, and increased vulnerability to both fire and subsequent conversion to grassland, scrub or agricultural lands (Uhl and Vieira, 1989; Asner et al, 2005; Nepstad et al, 1999; Abe et al, 1999; Verburg and van Eijk-Bos, 2003; Holdsworth and Uhl, 1997). What is known about the ecology of PNG's forest suggests that repeat logging within a short period also predisposes the area to grass invasion, fire and eventual conversion to scrub and grassland (Cameron and Vigus, 1993).

Several examples of forest loss and degradation associated with commercial logging are presented in Figures 21-26.

Are logged forests regenerating? The critical question

Central to the debate on the sustainability of logging native forest is whether or not logged forest is likely to regenerate. While some commentators insist that the impact of logging is small and that logged forests are likely to be ready for a repeated harvest within 30-40 years (Curtin, 2005) the results of this study paint a less optimistic scenario.

The large proportion of PNG's forests that has been degraded from its primary condition as a result of logging is of concern. This is because degraded tropical forests are vulnerable to conversion to non-forest cover by burning, further logging incursions, by new operators, local people with walkabout sawmills or by shifting cultivators (Holdsworth and Uhl, 1997; Lewis, 2006). Fire risk is greatly increased by dry weather (Lewis, 2006), and logging in seasonally dry regions is likely to result in burning of the degraded forest. The present study found large areas of forest in New Ireland, New Britain and Western provinces that had been logged and subsequently burned (see Figures 24-26).

Assuming the absence of catastrophic fires, the most critical factors in the maintenance of biodiversity in forests that have been selectively logged are the intensity of the logging operation and the time allowed for regeneration. It is likely that repeated logging of tropical forest before full regeneration has taken place causes permanent reductions in floral and faunal diversity. Claims that rainforest timber yields reach a steady state after 50-100 years of uninterrupted regeneration are mostly based on predicted yields from managed plantations located on optimum soils where the goal is to obtain a harvest with the shortest possible cycle (Vanclay, 1994).

The time taken for succession from logged forest clearance to forest resembling primary rainforest in biomass and species diversity has been variously estimated at 50 years (Kochummen, 1966), 50–80 years (Brown and Lugo, 1990), 73 years (Hughes et al, 1999), 150–200 years (Richards, 1952; Knight, 1975), 150–500 years (Riswan et al, 1985), 250–500 years (Kartawinata, 1994), 300 years (Enright, 1978) and 'centuries' (Whitmore, 1991). In PNG, it has been estimated that the regeneration of a climax state of maximum diversity may take up to 300 years or longer (Enright, 1978; Johns, 1986; Ash, 1988). Rainforest trees may live for hundreds of years – 150-250 years for fast-growing canopy species but 200-700 years for many slow-growing species and as much as 1000 years for some conifers such as *Agathis* sp. (Ash, 1981; Eckstein et al, 1981; Taylor, 1954). It is clear therefore that the transition to a state similar to that preceding logging may take a very long period. It is likely that it takes several hundred years for climax biomass to be reached (e.g. Enright (1978) suggests 300 years) and longer to reach a structure and composition resembling a primary forest. In this context, claims that the lowland forests of New Guinea can be sustainably logged on a 30-year rotational period should be disregarded (ITTO, 2007). A clear indication is that the logging companies do not seek to acquire concessions logged 30 years ago but only concessions offering primary forest. Indeed, 30 year rotations would only be sustainable if a tiny fraction of marketable large trees (e.g. <10%) were removed at each cycle – which would probably be uneconomic.

Of major concern from the present analysis is the extent of continued degradation and conversion of PNG's logged forest to other forms of vegetation and land use. The study found that overall, 23% of forest lands that had been logged were subsequently converted to non-forest cover, and therefore could no longer be classified as 'regenerating secondary forest'.

The study found that the longer a concession is allowed to be in operation, the greater the percentage of the logged forest area that will be converted. This analysis examined the extent of forest conversion for all PNG timber concessions over 10,000 hectares in size that have been in operation since 1972[3]. The data confirm that the older the concession the greater the percentage area that is converted. This relationship is apparent in Figure 20. This long-term analysis of the degradation history of all medium

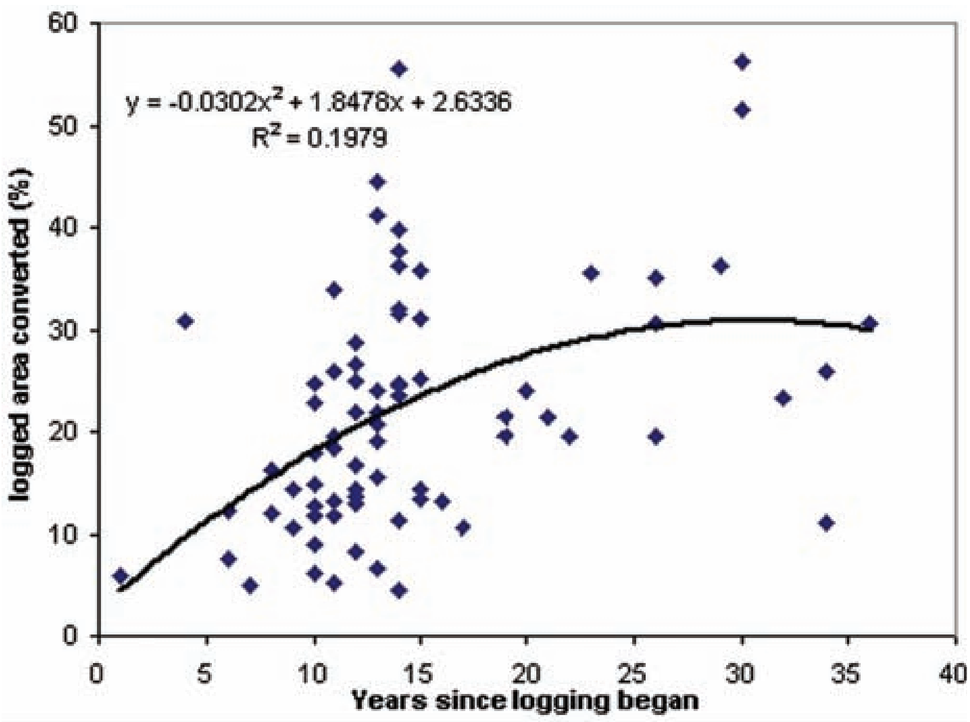
[3] *However the majority of these came into operation in the 1980s and 1990s.*

and large concessions establishes that deforestation does not plateau at 10-15% as would be expected if damage was restricted to the construction of roads and log ponds. Rather, it continues to increase over time, and in many cases continues for decades after logging has ceased. This is probably due initially to the post-logging death of residual trees, but later driven by repeated logging, the incursion of local people, fires, or the later conversion for other uses.

Contrary to forest industry claims (Curtin, 2005; Tate, 2007; Oxley, 2007), the results of the analysis suggest that logging practices in PNG have resulted in permanent damage to the country's forest estate. The general impoverishment of operating concessions was confirmed in a recent statement by Société Générale de Surveillance (SGS) who monitor PNG log exports, that "*The average log piece size across all sites has steadily declined. Mean log size in the first half of 2007 was just over half a cubic metre smaller than it was in 1996*" (SGS, 2007). Such statements contradict those of some industry commentators and should be a cause for concern for everyone interested in forest management in PNG.

On balance, there is little if any evidence to support the notion that PNG's degraded forests are successfully regenerating to their pre-logging state, while there now exists a reasonable amount of evidence suggesting the opposite is true.

Figure 20: The percentage of logged areas of each concession (>10,000 ha) that have been converted is compared with the number of years since logging began. The R^2 is 0.1979, which is significant ($F=18.75$, $p<0.01$).



Logging in commercially accessible forests and the outlook for the forest industry

A major reason why commercial export logging has been more widespread in the Mainland Lowland and Island regions of PNG is the greater accessibility of these forests. The analysis estimated that 13.5 million hectares of PNG's rainforest, 41% of 1972 forests, were potentially accessible to commercial logging, and that by 2002, 36% of these accessible forests had been degraded or deforested through a combination of logging and non-forestry processes. In 2002 the rate of deforestation in commercially accessible forest areas was 0.78% and the rate of degradation was 1.84%, amounting to a combined loss of 2.62% of accessible forest area per year.

The Islands provinces (excluding Bougainville[4]), where the oldest forestry concessions are located had the highest proportions (31-70%) of commercially accessible forests cleared or degraded due to logging over the 30-year period. It is clear that timber resources in the Islands provinces are close to being fully exploited – a fact now acknowledged by the Government of PNG (ODI, 2007).

The depletion of the forests of the Islands region encouraged the development of concessions in the mainland coastal lowlands (the Momase and Papua regions), and it is these forests that are subject to the majority of current logging activity. By 2002, between 11% and 63% of accessible forest in the Mainland Lowlands provinces had been deforested or degraded by logging. In Morobe, the Mainland Lowland province with the least extensive forests, the timber resources are close to being fully exploited.

The high rates and extent of deforestation and degradation of accessible forest areas suggest that timber resources in PNG may be commercially exhausted much sooner than previously estimated (FAO, 2005b; Wunder, 2003). While the present study records that 41% of potentially accessible forests had been logged by 2002, leaving 59% still available, almost 50% of the unlogged area had already been allocated in logging concessions and a significant proportion of this area is expected to have been logged already in the 2002-2008 period. The remainder occurs in relatively small blocks and in relatively remote, moderately inaccessible locations.

These findings complement a number of reports produced in recent years that have established, beyond all reasonable doubt, that the PNG logging industry is more akin to a 'timber mining' operation (ODI, 2007) than a well-managed, ecologically sustainable industry. A recent review by the International Tropical Timber Organisation (ITTO) found that PNG' s forest concession areas are not being sustainably managed (ITTO, 2007). Reports examining legal compliance have argued that the overwhelming majority of current industrial forestry operations in PNG are ecologically and economically unsustainable, and that many could be classed as 'illegal', as found by the government of PNG's own independent audits conducted between 2000 and 2005 (Schloenhardt, 2008).

Sustainability

In the debate over the future of Papua New Guinea's forests, forestry, reasonable levels of timber extraction and export, types of forestry operations and forest conservation measures, the concept of ecologically sustainable forestry has tended to be misunderstood or misapplied. A conservative definition of sustainable forestry is that an area of forest is logged so lightly and carefully that there is no significant change in the area's biological diversity or ecological processes. Logged forest would be allowed to completely regenerate before there is any further extraction The techniques employed would be able to extract mature trees from the forest when and where they reach some size that is both suitable for timber and sufficient to ensure recruitment.

[4] *In Bougainville there has been no commercial logging since 1988 due to civil conflict (Regan & Griffin, 2005) and records of the extent of logging prior to the conflict are unreliable. For this reason all forest clearance in Bougainville is recorded as not logging-related (34.04%) despite the likelihood that a proportion of this was logging-related.*

Applying this approach to logging PNG's lowland forest, the commercial yield of timber per hectare could be about the same as from current large-scale mechanized logging operations, but the harvesting would be done more slowly and carefully, over smaller areas, with significantly less wastage. Under such a regime, the ecological condition of the surrounding forest would be protected. There would be no 'salvage logging', and no return to the area until full regeneration had occurred – the biological reality being that this would take several human lifetimes.

By this definition, forestry operations in PNG are far beyond being ecologically sustainable. As they are designed to maximise financial return in the shortest time, operations are carried out at a larger scale and much more intensively, with more trees removed per hectare, and with considerably more wastage and collateral damage to the surrounding forest, land and waterways. Highly damaging salvage logging is widespread, there is no little active rehabilitation and repeat logging has been occurring after very short periods.

As a consequence, commercial logging as practised in PNG has a short future. In areas where logging was first established, such as in New Britain, the vast majority of accessible forest has now been logged more than once and the resource is depleted: yields are declining and the industry is shifting elsewhere (GoPNG, 2005). The remaining forest areas are irreparably damaged and, rather than being rehabilitated, are more likely to become further degraded and the land converted to non-forest use. Forestry has not been developed as a sustainable industry for New Britain, but has been a short-lived, one-off opportunity for logging companies, who have made little or no re-investment in the area.

The present study has mapped the rapid replication of this approach across the entire country. It estimates that most accessible forest areas are within existing logging concessions, and that by 2002, 36% had already been logged and degraded by this type of forestry operation. It is not clear how long current mechanized logging practices can be maintained in PNG. The answer depends on numerous factors, including the amount of accessible forest remaining; international timber prices – if timber prices rise relative to costs, loggers can remove more logs per hectare and smaller concessions in marginal areas become profitable. Conversely, PNG's forests are becoming increasingly prone to burning, and, following the same pattern as Indonesia or the Amazon, may suffer catastrophic fires at some point in the near future.

Nationally, the Government has sought a 'sustained yield' of timber from the country's forests, a much lesser goal than ecologically sustainable forestry. However even this goal is far from attainable under current strategy. The results of this study indicate that areas of accessible forest across the country are being progressively degraded, with little attempt to limit the intensity of logging or the extent of collateral damage, nor extend the return time to levels that would allow the forest to produce a sustainable harvest of timber.

To achieve such a goal would require a deliberate change of strategy. Suitable areas of land would have to be assigned to perpetual timber production and, through appropriate silvicultural techniques, managed to optimise the growth and repeated harvest of selected tree species. The production forest areas would be more akin to multi-species timber plantations than native rainforest. Biodiversity would be much reduced but timber production would be enhanced.

How much of PNG's land should be converted to such production forests, affecting which areas, which catchments, and which communities? What proportion of each type of PNG's unique forest should be conserved and how are these areas best protected from logging, burning, and clearance for agriculture, plantations or other developments? These questions are best answered through adequate country-wide land-use and development planning processes. It is hoped that the data obtained through this study will be used to inform a rational planned approach to an ecologically sustainable future for PNG.

Sustainability and the volume of log exports

In a further analysis relevant to the present study, the UPNG Remote Sensing Centre compared the volumes of timber exported and the areas of forest logged in 13 logging concessions that began operations after 1992. It was found that these concessions exported an average of 13 m^3 per hectare of merchantable logs between 1993 and 2005. Calculations were made also of the total amounts of timber that had been removed or killed from these concessions, including the volumes damaged by roading, skidding, log landings and during felling (Abe et al, 1999; Nepstad et al, 1999; Verissimo et al, 1992; Cameron and Vigus, 1992) and the amounts, estimated by FAO to be 10-35% in PNG, of potentially merchantable logs that were cut but not exported due to defects, and were either left at the side of the wharf, burned or sold locally as sawn timber (FAO, 1992).

It was estimated that the average log volume removed from these logging concessions between 1993 and 2005, including the potentially merchantable logs which never make it to export, and the non-merchantable trees killed, was 86-92 m^3/ha. It was further estimated that the total wood volume of all trees killed through logging activity (degradation plus deforestation), including the non-merchantable parts of the tree as well as the log, was on average between 196 and 210 m^3/ha or about 27-29 % of the total forest wood volume (see Annex 2). These estimates suggest that to generate the 2007 export volume of 2.8 million m^3, approximately 18-20 million m^3 of logs would have been killed or extracted. When the volume of the whole tree rather than only log volume is included, then 42-45 million m^3 of wood was killed or extracted to produce an export volume of 2.8 million m^3. This suggests that the use of export volume as the absolute measure of logging sustainability is misguided, because the export volume is only a fraction of the actual volume that is destroyed.

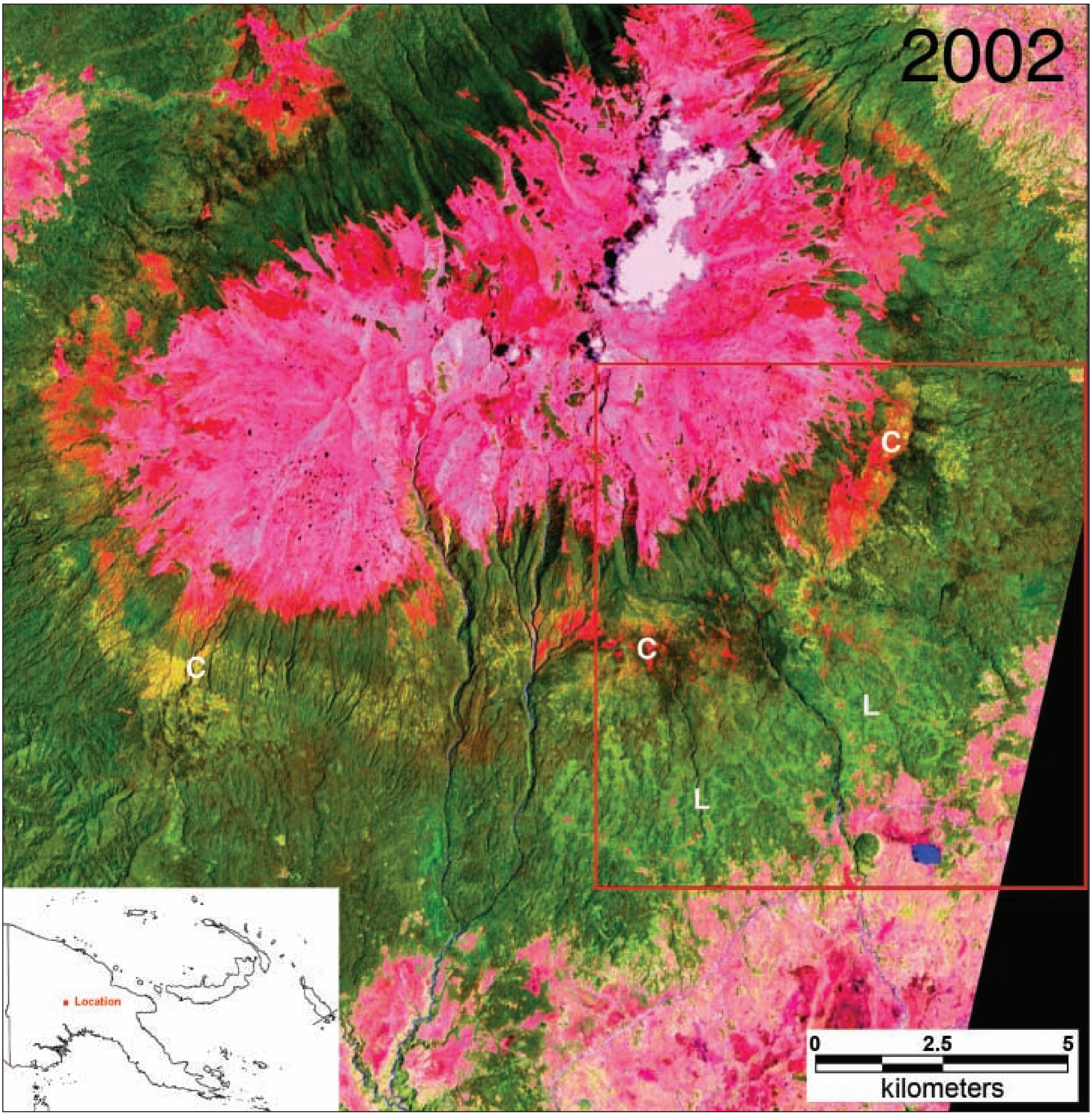
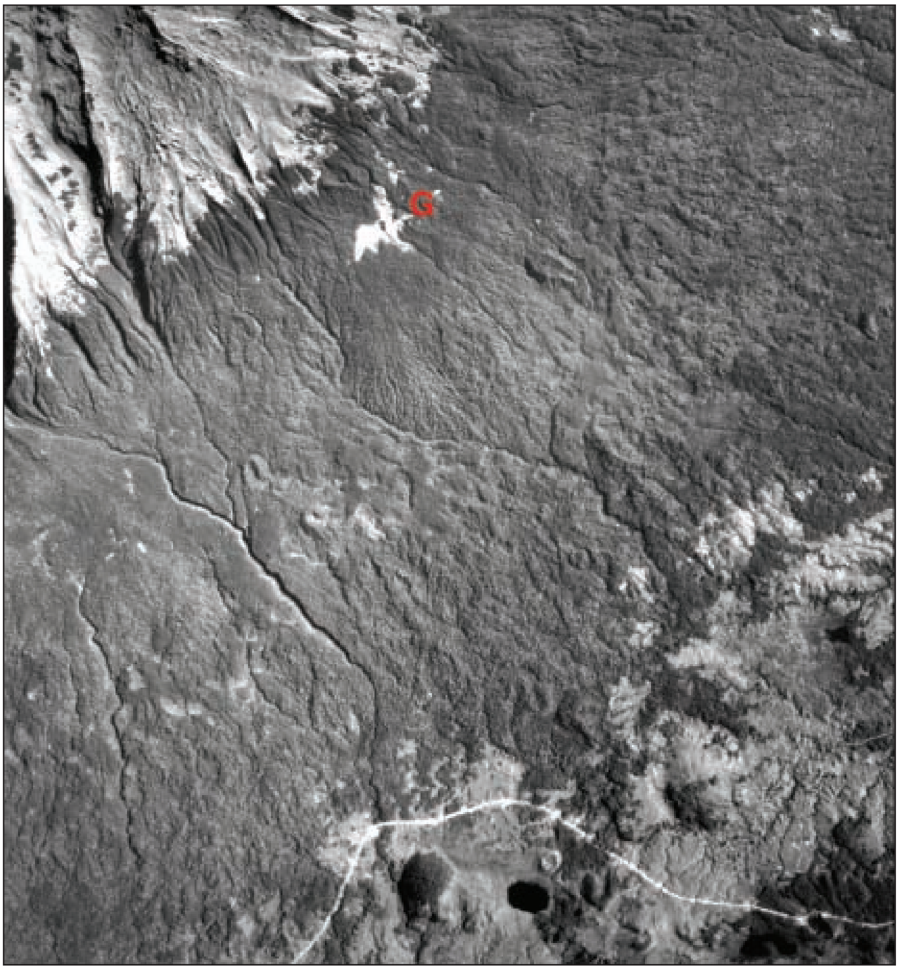


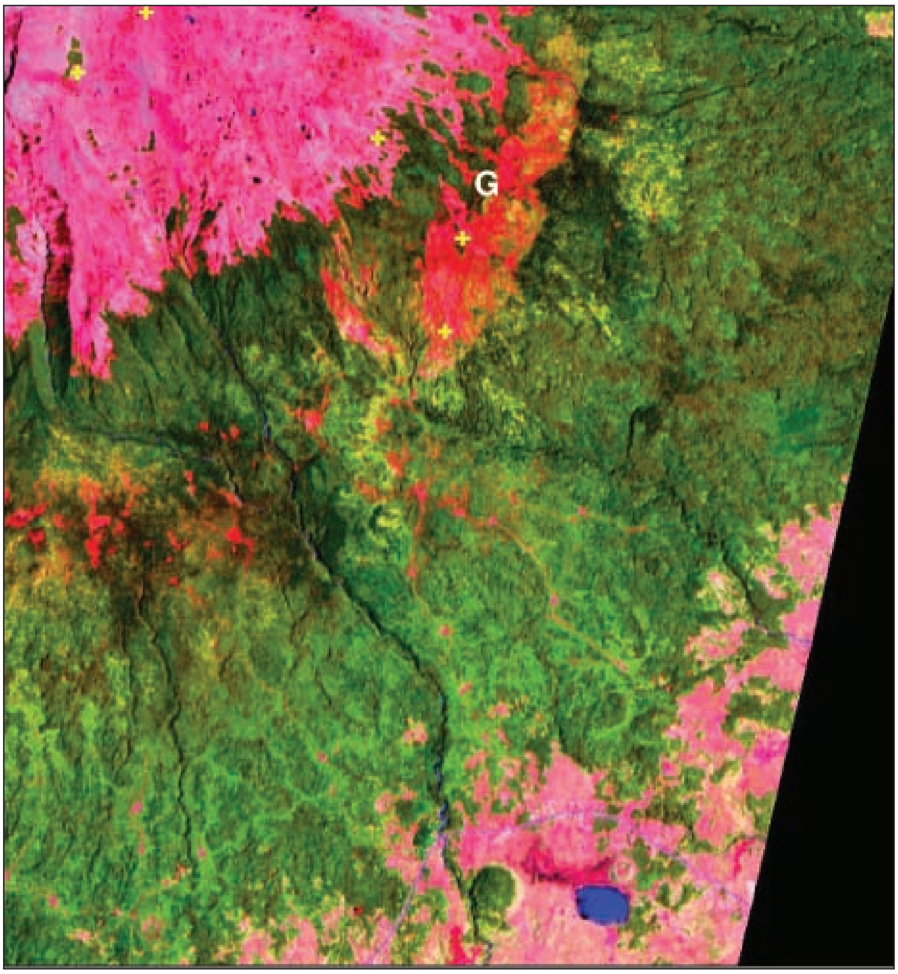
Figure 21: Mt Giluwe (4,367 m) on the border of Western Highlands and Southern Highlands Provinces has been subject to several logging operations in the late 1980s and 1990s. Above is a SPOT4 image taken in 2002. Grassland is generally shown in red hues and forest cover in dark green.

A network of logging tracks is visible in the lower half of the zone bounded by the red box and marked with the symbol **L**. Substantial areas of forest, that probably were stands of *Papuacedris* sp (pers. comm. Dr J. Ash), have been clearfelled at the treeline (2,950-3,100 m). These areas are marked with the symbol **C**.

On the facing page, the area bounded by the red box is magnified and shown in both a 1972 Skaipiksa photograph and in the 2002 SPOT 4 imagery. The area of grassland marked **G** in the 1972 photograph and satellite imagery has expanded through logging and subsequent burning. Fires locations, recorded as 'Hotspots' in 2003 and 2004 are displayed on the 2002 imagery with the symbol +. Two of these fires occured in this cleared area.



1972



2002

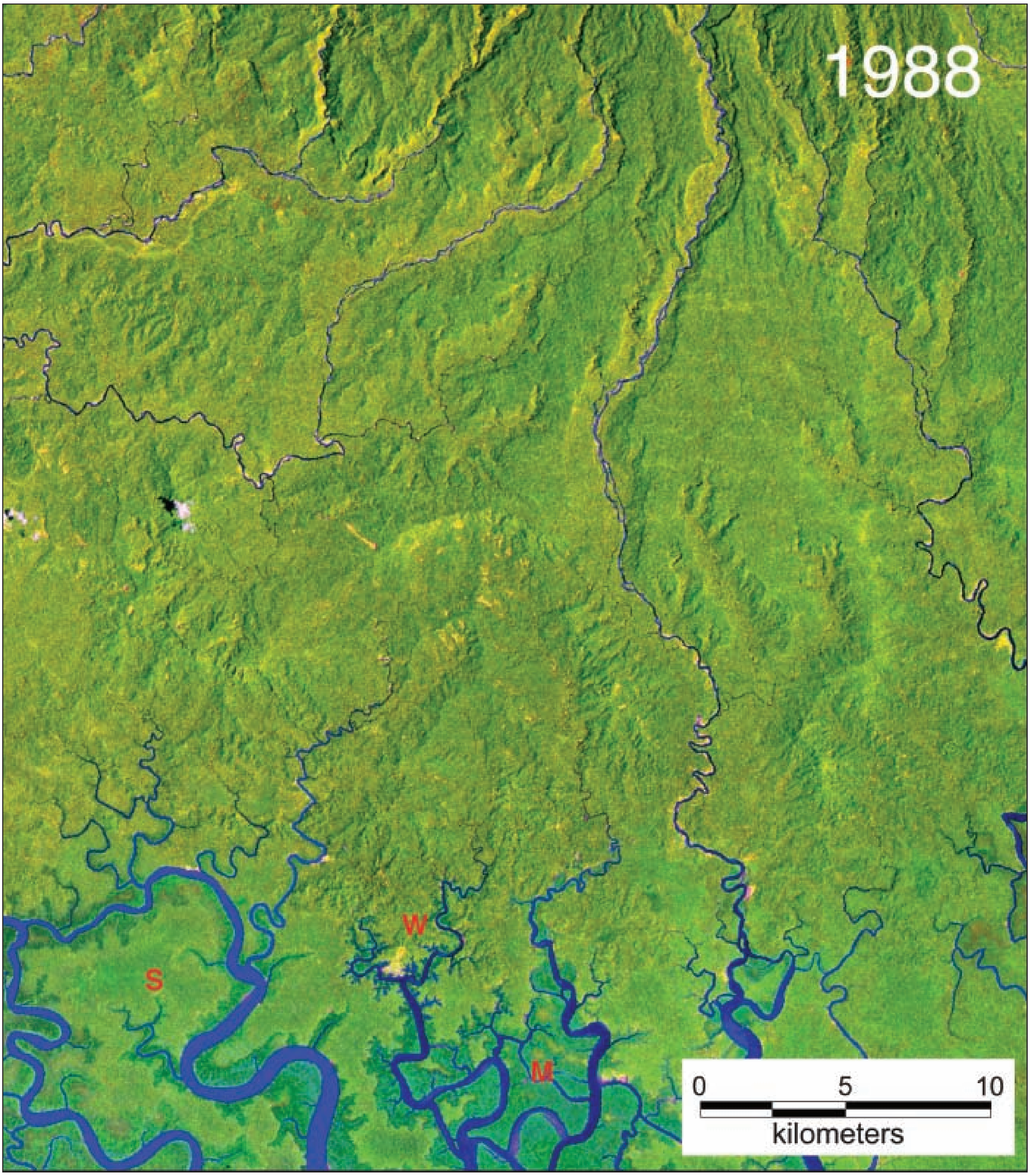
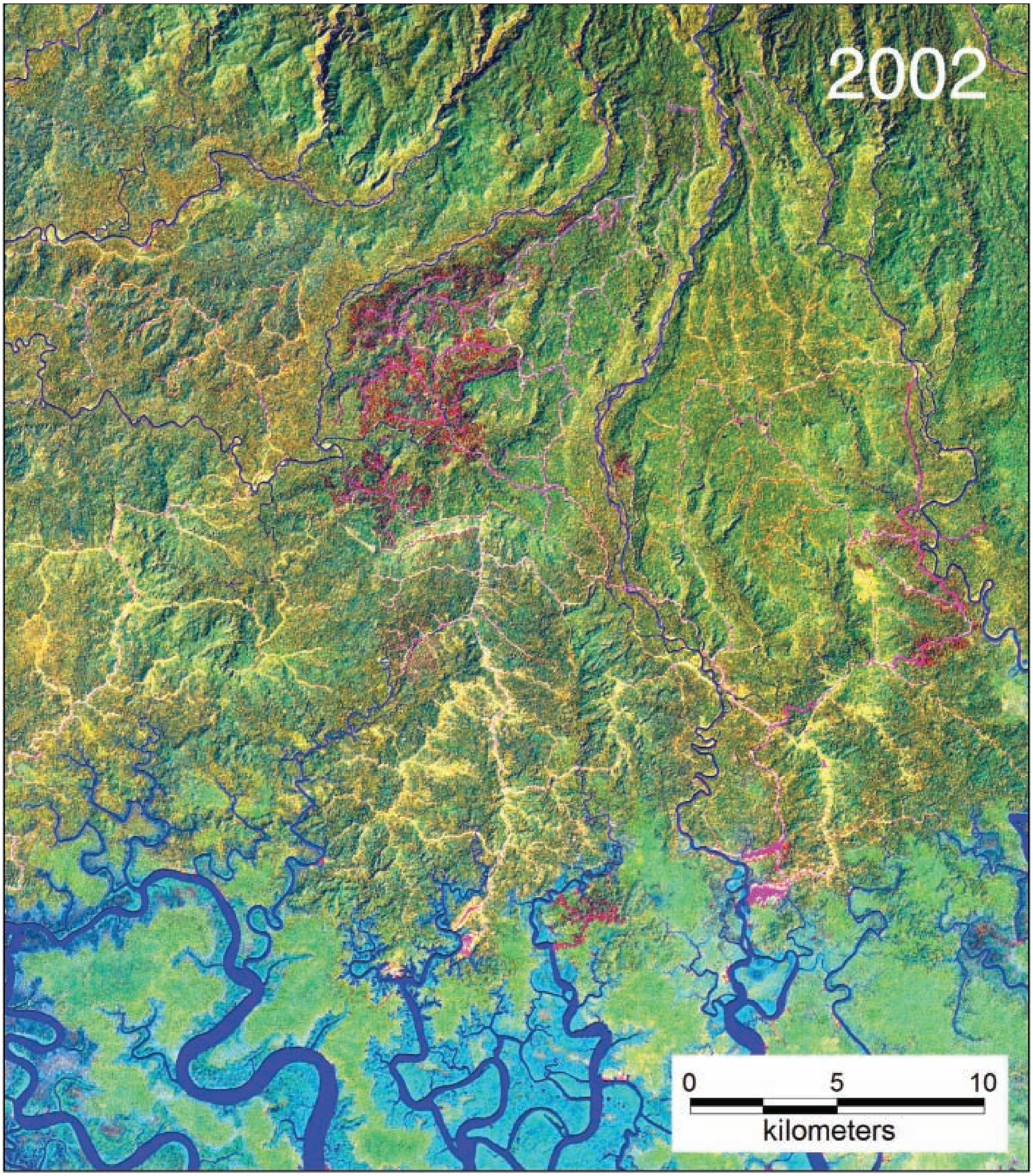


Figure 22: A section of the East Kikori logging operation in Gulf Province. Above, a Landsat TM image from 1988 shows intact primary rainforest across most of the image. Areas of Swamp Forest (**S**) and Mangroves (**M**) are visible in the southern portion of the image. The village of Wowoubo is located with the symbol **W**. The Landsat ETM+ image on the facing page shows the effects of the logging operation that began around 1995. The roading of the logging operation is clearly visible as are areas of deforestation associated with log ponds and high intensity cutting. The network of tracks and associated damage is typical of lowland logging operations.


2002
0
5
10
kilometers


Location

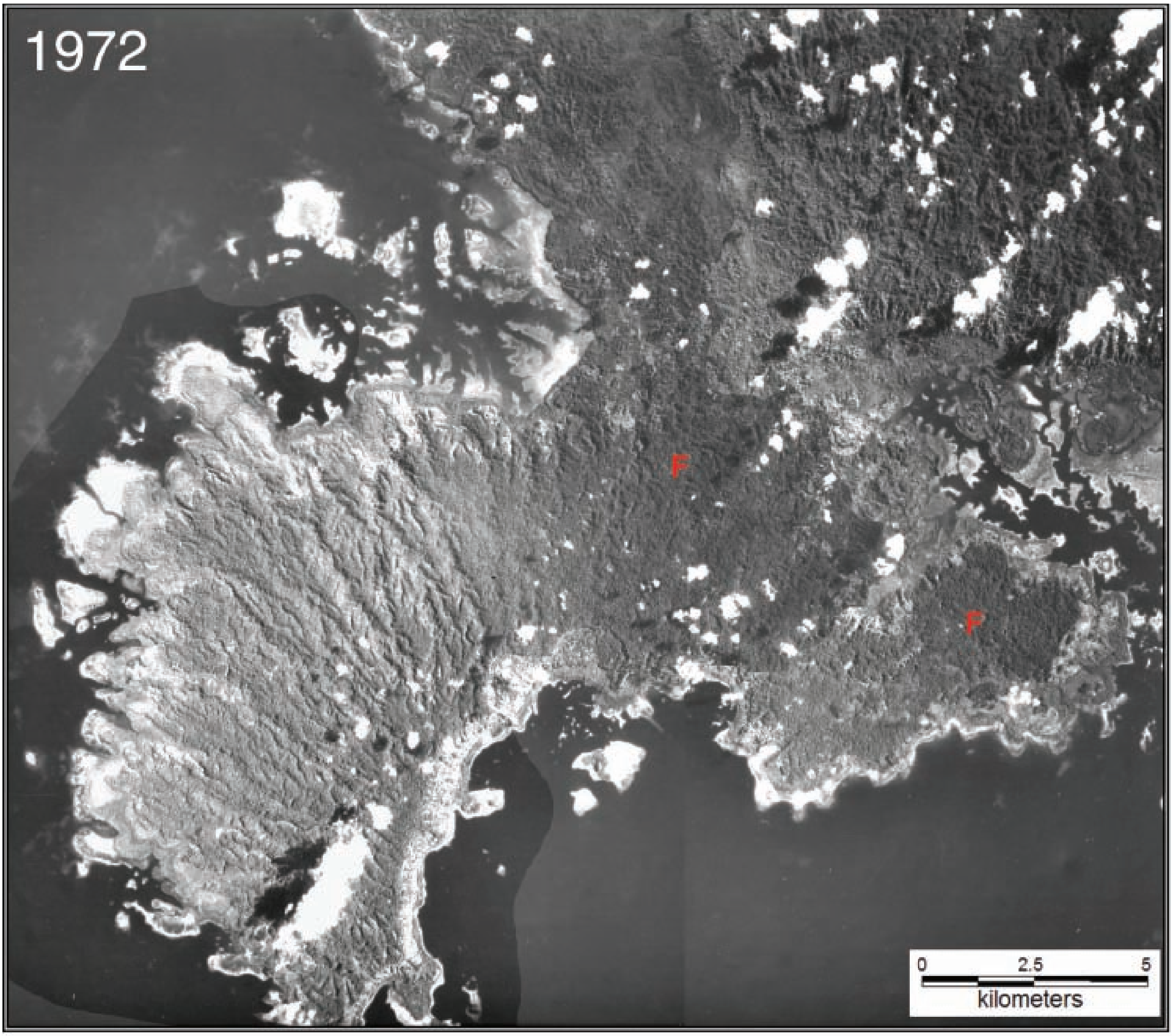
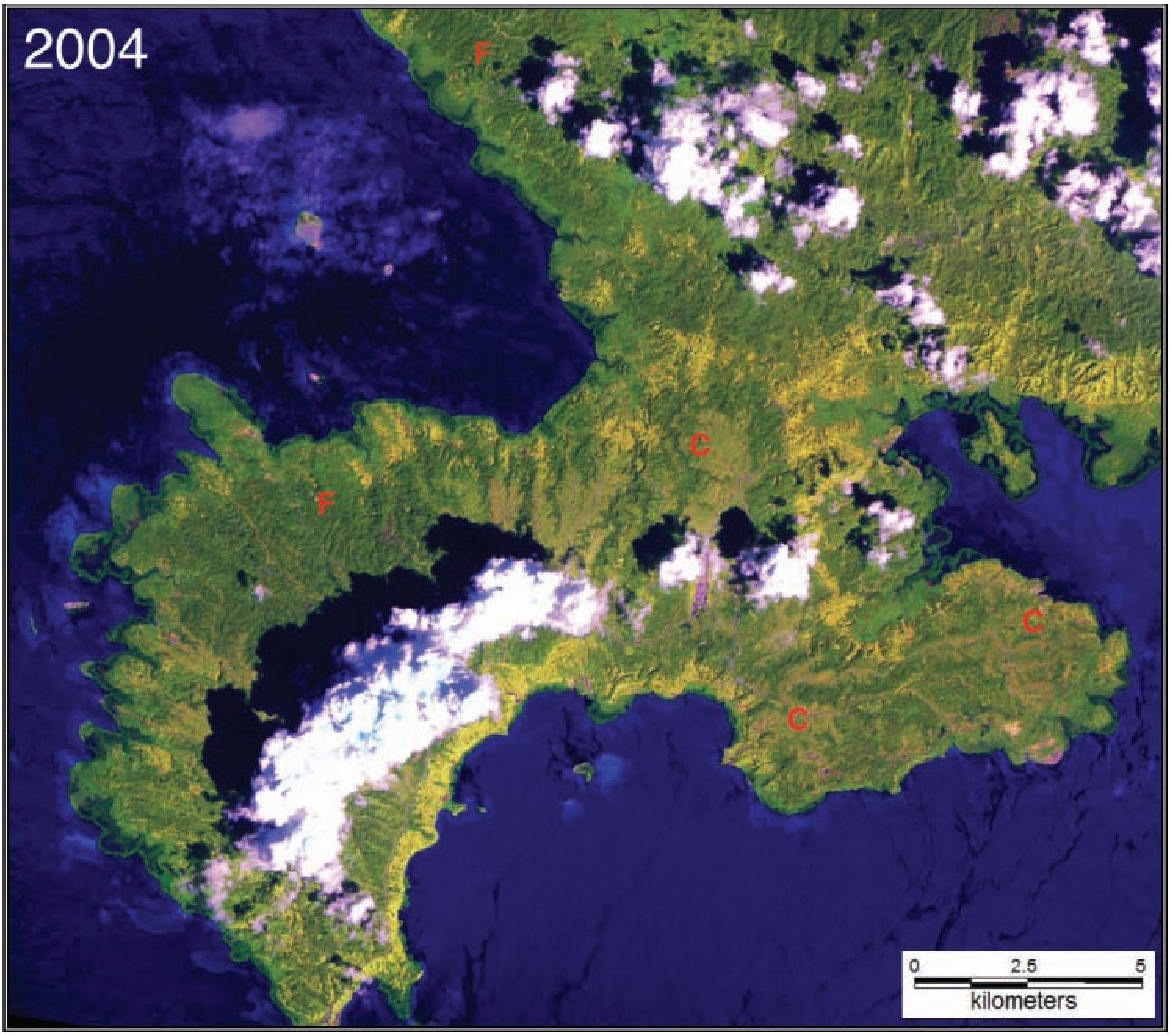


Figure 23: Logging in the south-west of Manus Island.

Above, a Skaipiksa photograph from 1972 shows the majority of the landscape covered with Intact Primary Forest (**F**). Clouds are visible as white areas scattered throughout the image.

Right, a SPOT4 image from 2004 shows the impacts of logging activity which has focused on even aged stands of *Calophyllum* (Hammermaster and Saunders, 1995) that dominated this area. Many of these sites have essentially been clearfelled. These are marked with the symbol **C**. Remnant areas of intact primary forest (**F**) are also visible. Clouds obscure areas of the image.

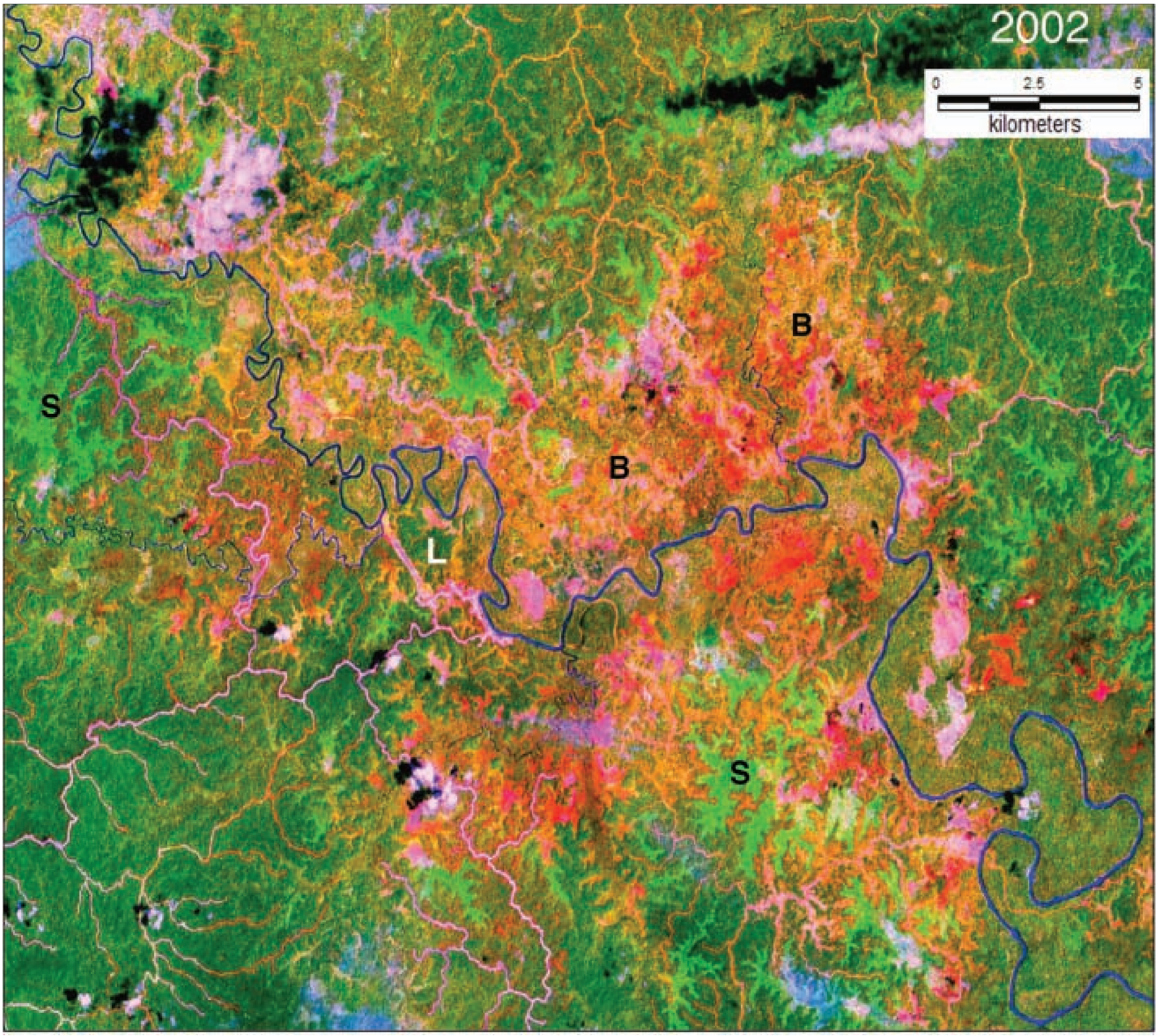

2004
F
F
C
C
C
0
2.5
5
kilometers


Location

Figure 24: Logging around the Wawoi River, Western Province.

Above: a Skaipiksa photograph from 1972 shows a mixture of intact primary forest (**F**) and swamp forest (**S**). Clouds are visible as white areas scattered throughout the image, and are concentrated on the right. No human activity is visible.

Right: a SPOT4 image from 2002 shows the impacts of a decade of logging activity, centered on the Sasereme Logging Camp (marked **L**). Swamp Forest (**S**) as well as logging tracks radiating away from the river are clearly visible. Many areas have been logged repeatedly and have also been burned. Areas that have been burned generally possess an orange hue. Examples of burned forest are shown with the symbol **B**. Note how logging has not entred areas of swamp forest.


2002
0
2.5
5
kilometers
S
B
B
L
S


Location

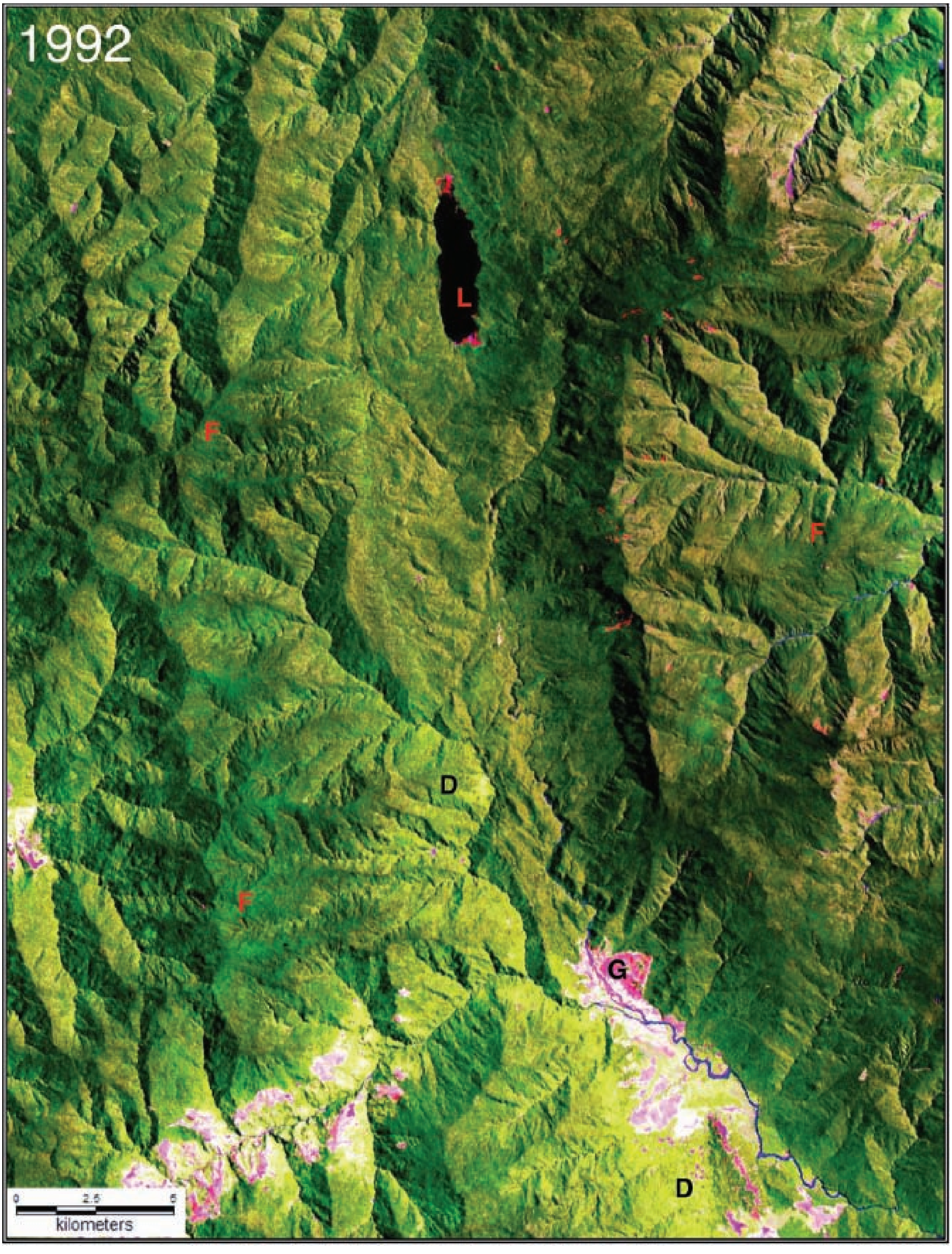
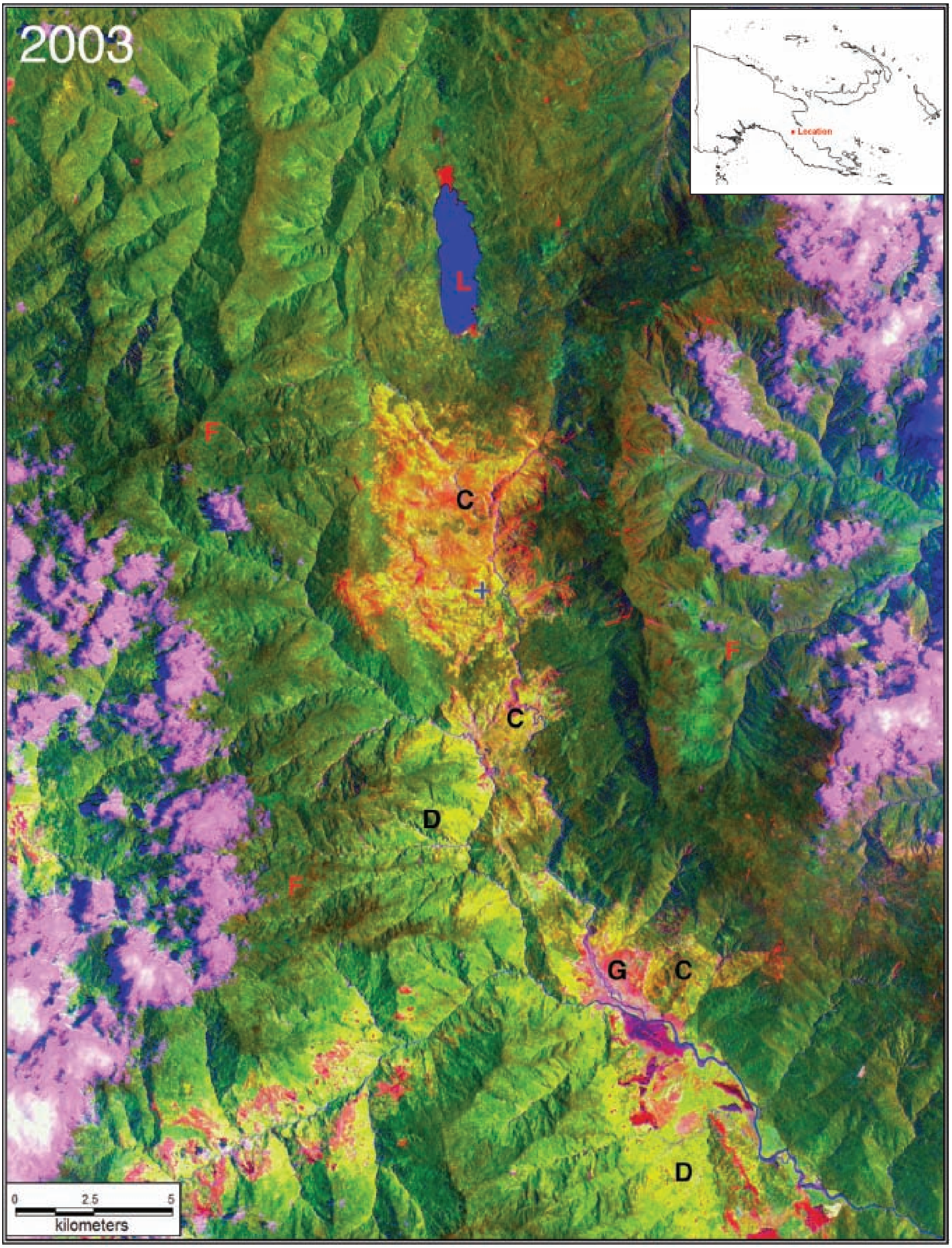


Figure 25: Deforestation in the Lake Trist region of Morobe Province. Above a Landsat TM image from 1992 shows Lake Trist (**L**), Intact forest (**F**), Scrub (**D**) and Grassland (**G**). On right, a Landsat ETM+ image from 2003 shows Lake Trist (**L**), Intact Forest (**F**), Scrub/gardens (**D**) and Grassland (**G**). At least 25km^2 of forest has been cleared to the south of Lake Trist, and in areas to the south. Areas of deforestation are marked with a **C**. The NFA has expressed the opinion that these forests have been commercially clearfelled despite not being in a recognised Forest Management Agreement (FMA) zone.



For a fire to be the primary cause of the deforestation seems unlikely. The location of recent (2006) fires is recorded with the symbol +, suggesting that burning has followed logging as a secondary form of site degradation. This example of large-scale forest-loss suggests that the claim that all commercial logging operations are legally mandated, or occur within FMA boundaries, is in this case demonstrably false.

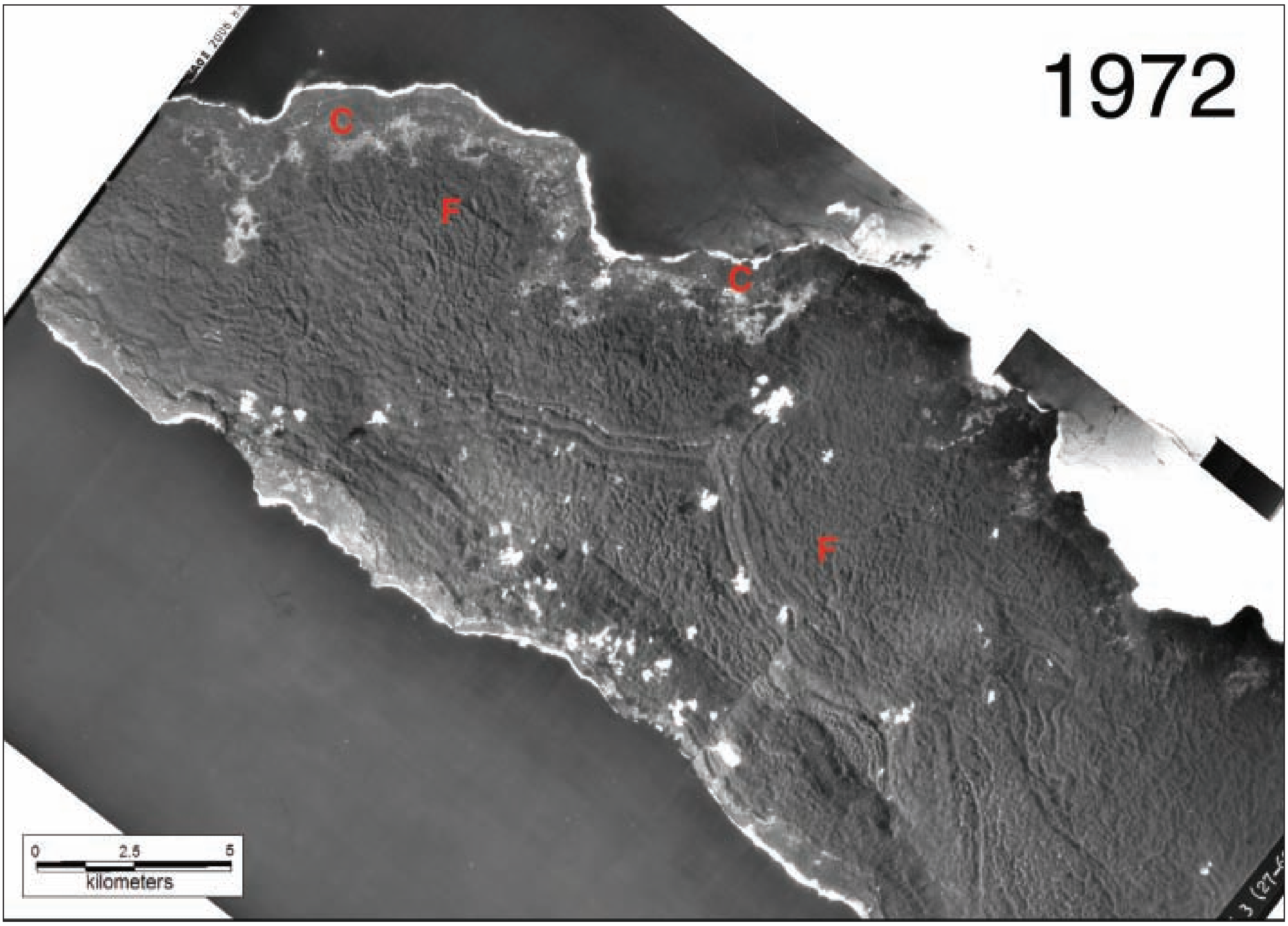


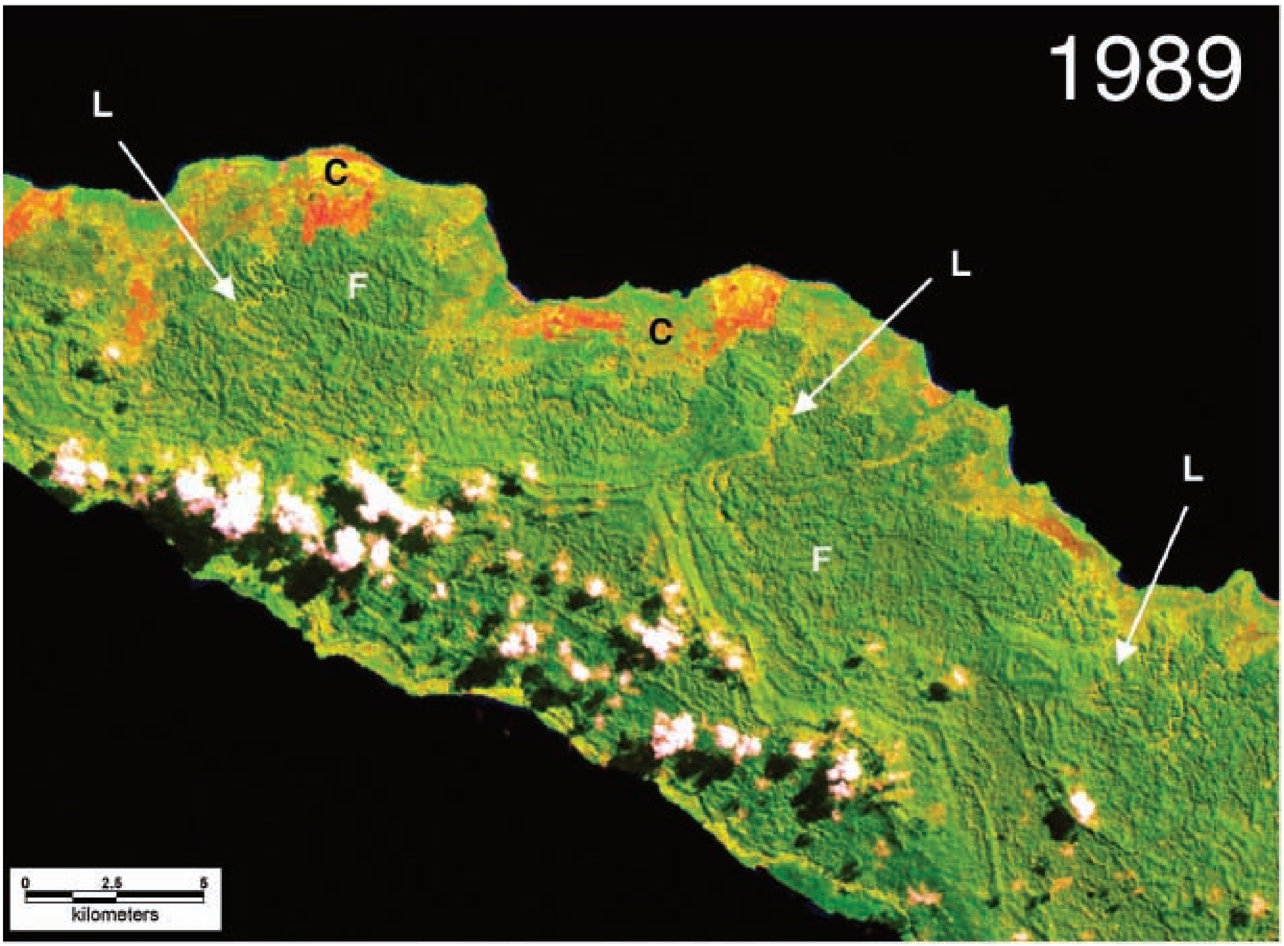
Figure 26: Deforestation in central New Ireland.

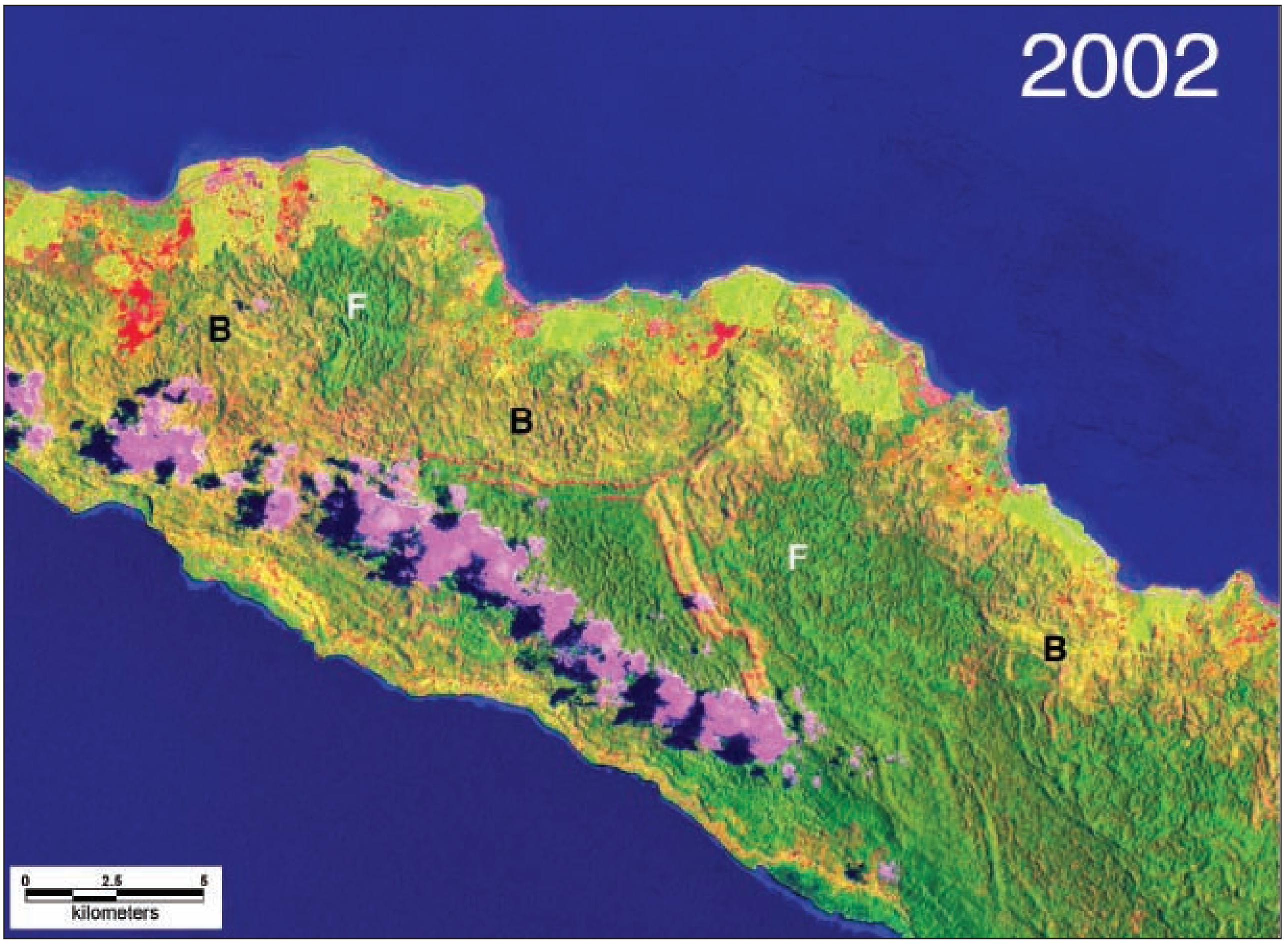
Above, a mosaic of Skaipiksa aerial photos shows the extent of forest cover in the Falangawa Bay area of central New Ireland in 1972. Intact Primary Forest (**F**) covers much of the upland karstic terrain. Areas that had been cleared (**C**) for plantations are visible in the coastal regions.

Above right, a Landsat TM image from 1989 shows logging roads beginning to enter the forest, particularly from the north coast, working their way south (**L**). Logging continued throughout this area during the early 1990s.

In 1996, fires that began in areas of coastal grassland entered forest areas - large areas of forest were burned. The extent of these burned forests (**B**) are still visible in a Landsat ETM+ acquired in 2002.

There is a correlation between areas that were logged in the 1989 image and areas that were burned in the 2002 image, suggesting that logging may have predisposed these forests to burning.


1989
L
C
F
L
C
L
F
0 2.5 5
kilometers


2002
F
B
B
F
B
0 2.5 5
kilometers

3.3 Forest fires

Tropical forest fires are increasingly understood to be significant drivers of forest change (Cochrane, 2003), with three main factors recognised: first, a forest's vulnerability to fire is enhanced greatly by forest habitat fragmentation caused by logging or garden clearing; second, high human population densities, especially in areas of degraded forest, greatly increase the number of ignition sources; and third, drought periods, associated with El Niño and global warming impacts are becoming more frequent and severe. In high altitude areas, drought produces clear nights that cause frost damage, which also leads to increased flammability of vegetation (Laurance, 2003; Allen and Bourke, 1997). It has been estimated that forest fire emissions in 1997-98 may have released a volume of carbon dioxide into the atmosphere equivalent to 41% of annual fossil fuel burning world-wide (Goldammer, 1999). It is predicted that pan-tropical forest fires will increase as the world's rainforests become extensively degraded and less fire-resistant.

Evidence from tropical rainforests worldwide suggests that selective logging increases a forest's susceptibility to fire (Cochrane et al, 1999; Uhl and Buschbacher, 1985, Holdsworth and Uhl, 1997). The 1997-1998 fires in Indonesia primarily affected recently logged forests; primary forest and those forests logged several decades previously were less affected (Siegert and Hoffmann, 2000). The fires severely damaged the logged forest areas, leaving large amounts of dead flammable wood, thereby increasing significantly the risk of recurrent fire disasters (Siegert et al, 2001), possibly for decades after the logging activities have ceased. In the Amazon, recurrent fires have been found to have more severe impacts than those of the initial conflagration (Cochrane et al, 1999).

The present study found that of the total forest loss between 1972 and 2002, 4.4% or 347,079 hectares was due to large forest fires. While fires occurred in most provinces the largest proportion occurred in Western Province, where 150,829 ha were burned. Many of the fires assessed in the present study, including those during the 1997-1998 El Niño drought, were associated with subsistence agriculture. Clearance of land for subsistence agriculture frequently involves burning, which commonly spreads into adjacent forest vegetation.

At high altitudes, burning was the most important driver of forest loss between 1972 and 2002. 13% of the country's upper montane forests were destroyed over this period, in most areas as a result of fire. It is likely that the fires were lit by people, especially during the 1997-1998 drought. High altitude forests and grasslands are not used for logging or subsistence agriculture but are sources of wild food, especially when crops fail due to drought and associated upland frosts. High altitude grasslands in PNG are relatively flammable and, during droughts, grass fires ignited by humans or lightning have been recorded spreading into adjacent forests, causing the death of trees (Paijmans and Loffler, 1972).

Mountain ranges that have suffered especially large losses of montane forest in the study period include the Star Mountains (West Sepik), the Kubor Ranges (Western Highlands), the Muller Ranges (Southern Highlands), the Saruwaget and Finisterre Ranges of the Huon Peninsula (Morobe Province) and the Owen Stanley Ranges (Central Province). Examples showing forest loss in several of these locations are presented in Figures 28-33.

The relationship of climate change to the management of the forests is one that has not received adequate attention in PNG – particularly in relation to enhanced El Niño events and their potential to catalyse forest fires. Given the large areas that now exist of degraded forests punctuated by roads, the potential for future widespread fire-related conversion should be viewed with concern (Nepstad et al, 1999). Logging activity has primed these areas for the conduction of fire. The areas at most threat from the combination of logging and fire are those in Western Province and the Gulf-Western border where a seasonally-dry period (McAlpine et al, 1983) makes them more susceptible to burning than many other areas of the country. These forests would be particularly vulnerable to conversion to savannah or grassland if wide-scale commercial logging and subsequent burning were to occur. In montane regions, further burning has the potential to destroy a significant proportion of the remaining high-altitude forests.

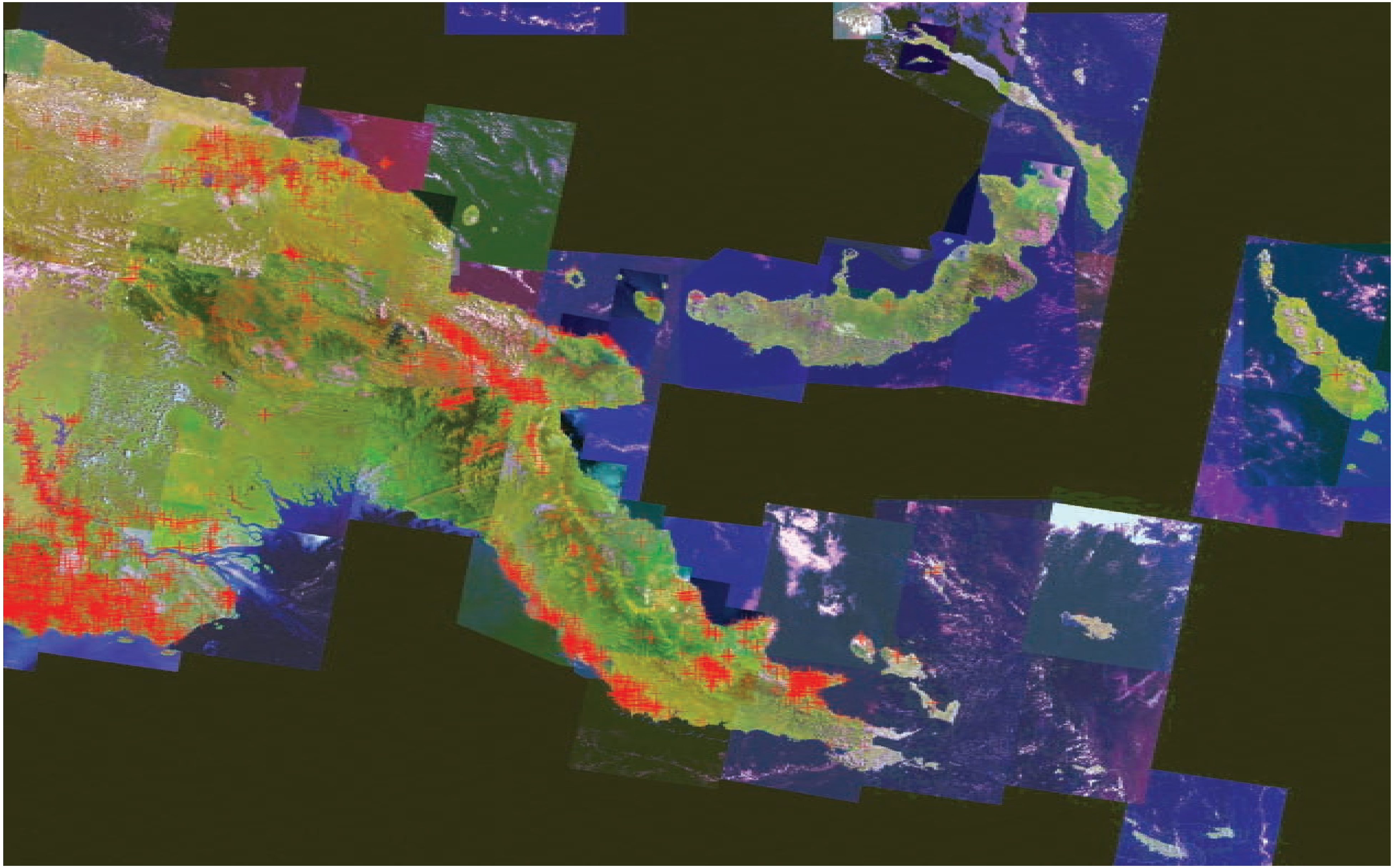


Figure 27: The location of large fires (and some volcanic eruptions) recorded over 2006 are indicated with the symbol +. While the majority of fires are located in the seasonally dry savanna woodlands of southern Western Province, South East Papua and the relatively low rainfall areas of the Markham Valley, other fires are recorded in most areas of grassland throughout the country. Occasional forest fires are also recorded. It is clear that in PNG large fires are a regular phenomenon. These locations were derived from the MODIS satellite sensors which is © Commonwealth of Australia (2006). It is estimated by the UPNG Remote Sensing Centre that these records represent approximately only a small proportion (≈10%) of the total number of large fires that occurred in 2006.

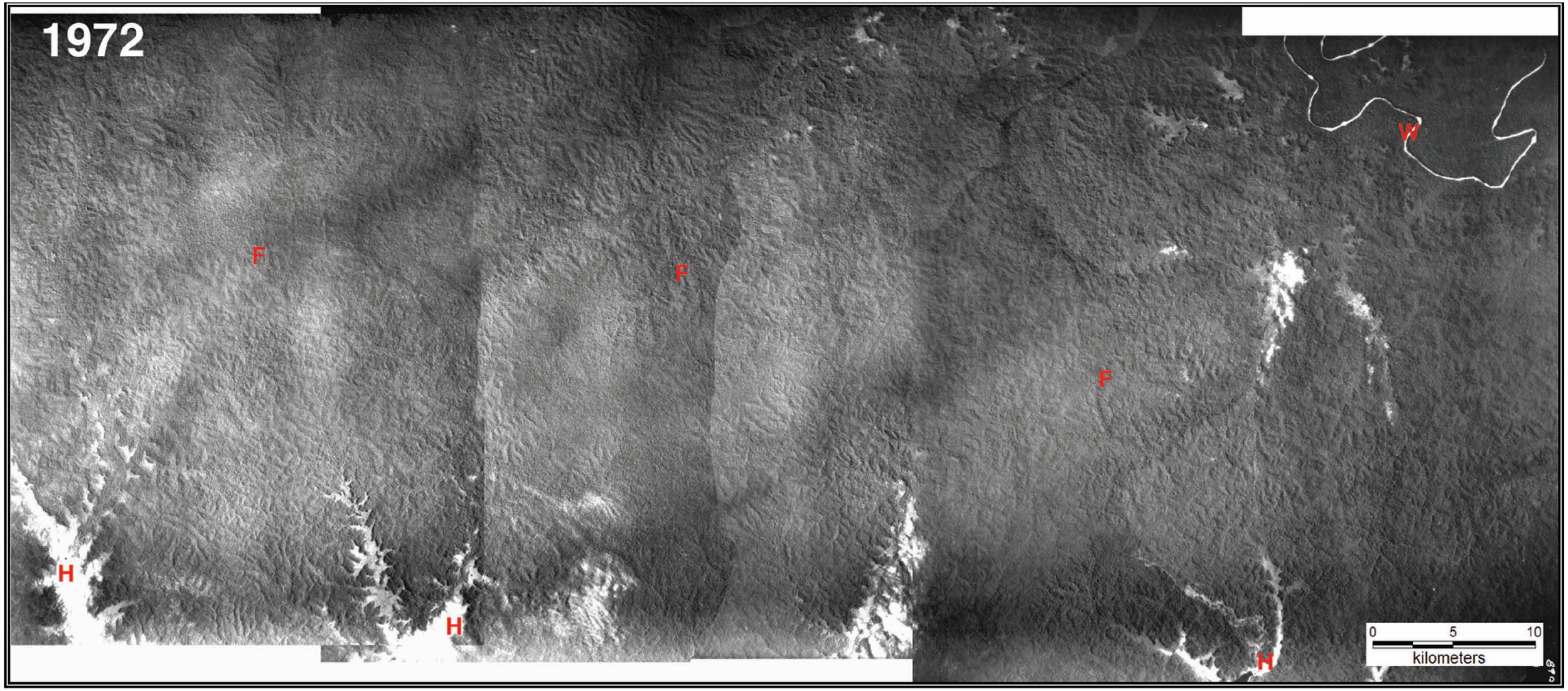
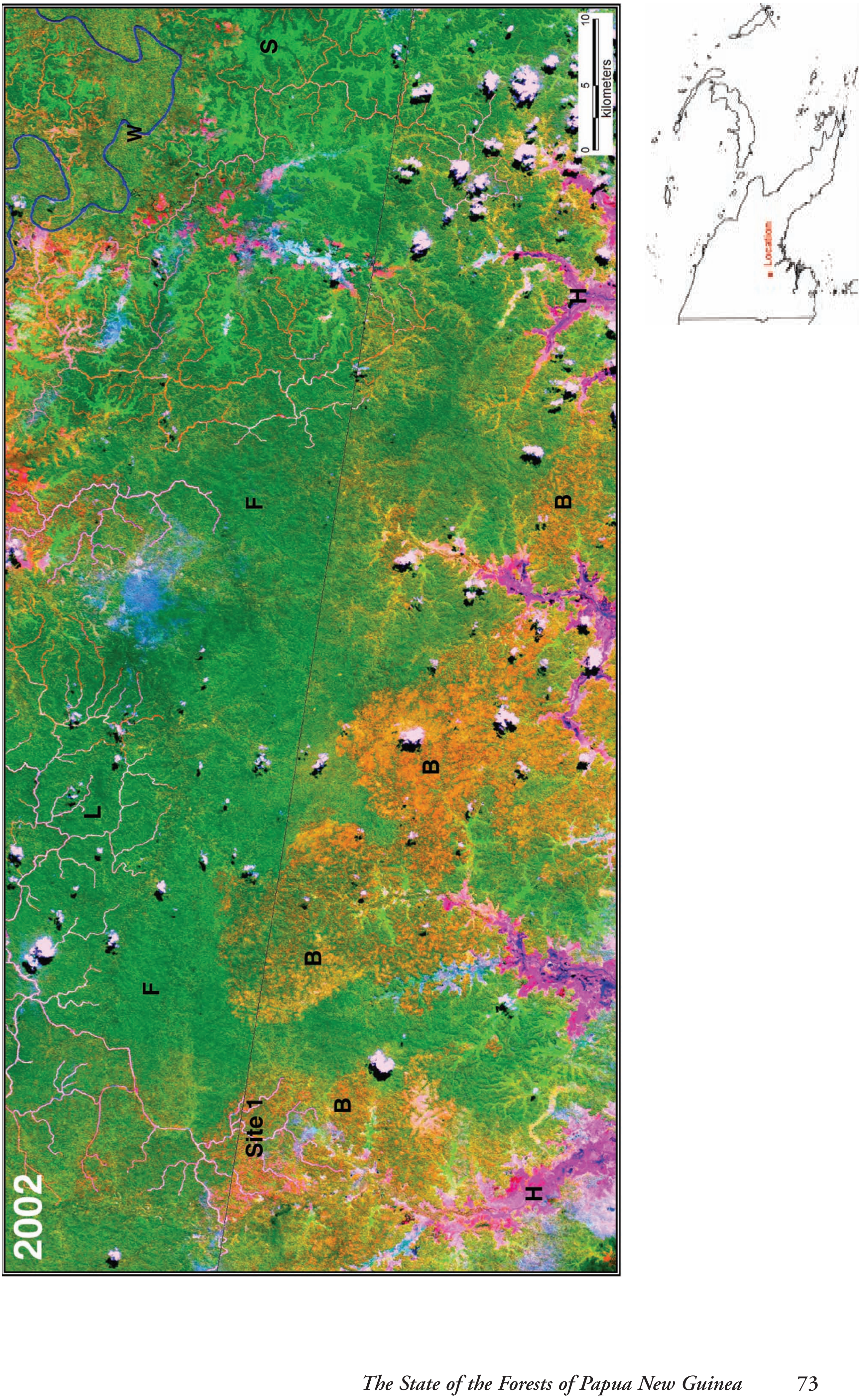


Figure 28: The above image is a mosaic of SkaiPiksa aerial photographs of the area between Balimo and the Wawoi River in Western Province taken in 1972. The Wawoi river is located in the top right (**W**). The majority of the mosaic is Intact Primary Forest (**F**). In the southern areas of the image areas of Swamp Grassland (**H**) are visible. The same region is shown below in a SPOT4 image taken in 2002. In this image, the Wawoi River is visible (**W**), as is Intact Forest (**F**), Swamp grassland (**H**), and Swamp Forest (**S**) (which is difficult to distinguish in the 1972 photograph). A network of logging roads of the Makapa FMA is visible as white/pink lines in the northern half of the image (**L**). Large areas of forest in the centre and lower areas have been burned (**B**). These fires occurred during the dry 1997/1998 El Niño period. The burned status of this forest has been confirmed by NFA visits to Site 1 where harvestable timber volumes were found to be very low or non-existent. These fires probably began in Swamp Grassland and progressed north. Fire hotspots have been recorded regularly in these Swamp Grassland areas.


2002
Site 1
W
S
F
F
L
B
B
B
B
B
H
H
0
5
10
kilometers
Location

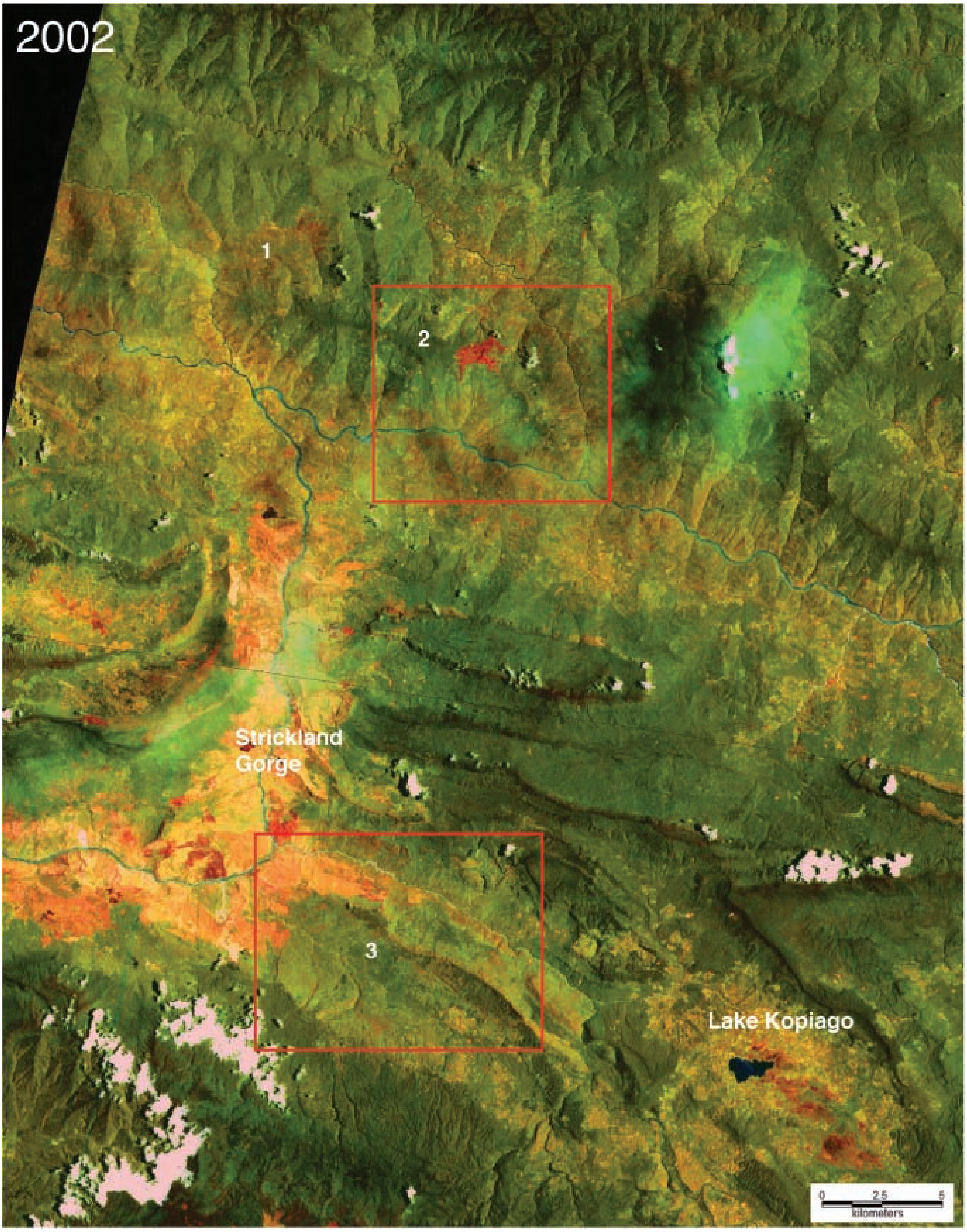
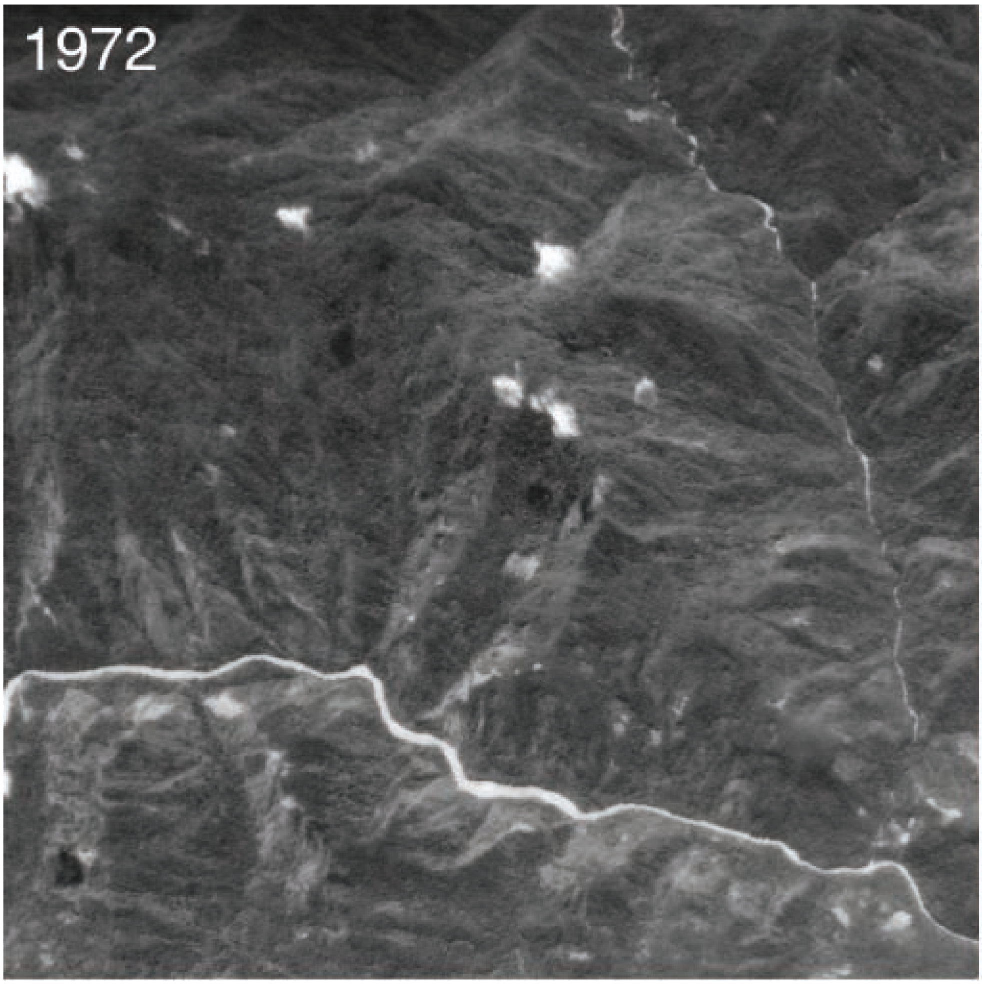
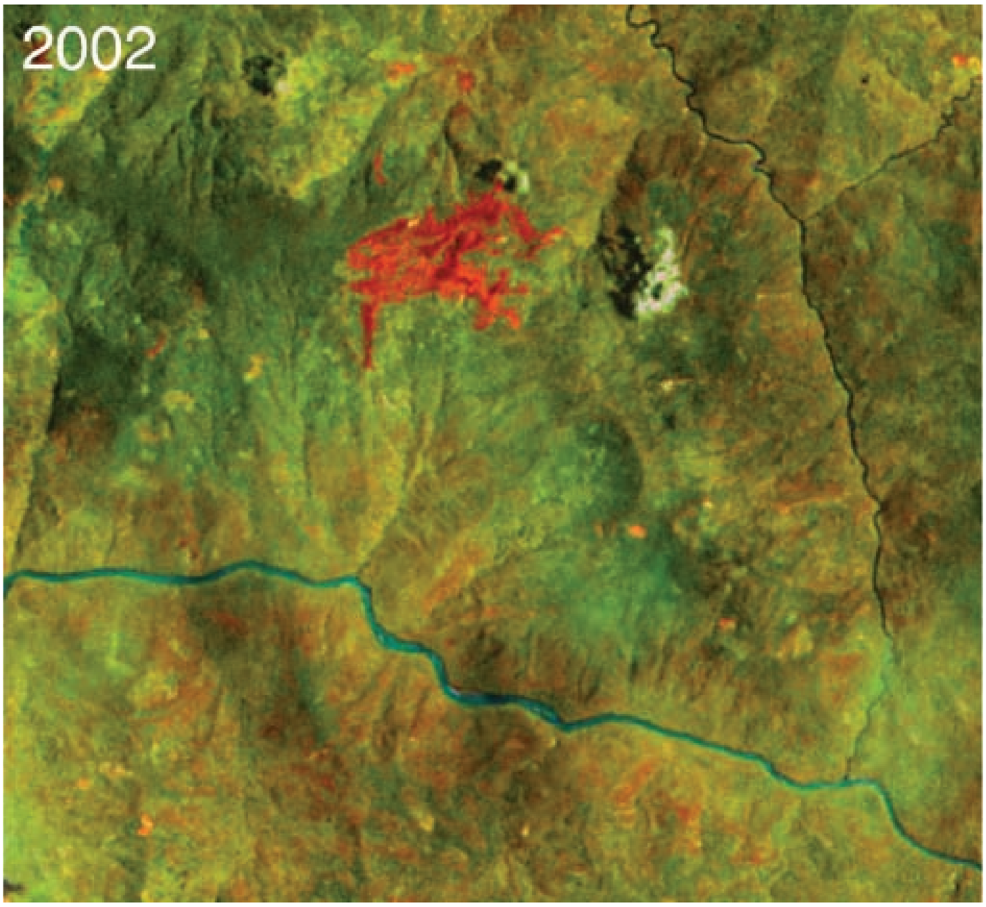


Figure 29: The Strickland Gorge and Lake Kopiago. While the Gorge area has long been grassland, the combination of expansion of subsistence agriculture in its upper reaches and extensive forest fires in 1997/1998, resulted in large areas of conversion and degradation. The extent of burning can be seen at location 1 where the vegetation cover is brown in colour, distinct from the dark green forest to the north. The insert at 2, magnified on the right, shows how a new area of grassland (in red) has been created at this location. Hotspots show that it has been burned regularly in the last few years. The insert at location 3, magnified on page 76, shows how a large area of forest has been converted to scrub through burning.





Thse two images show the area demarcated as insert 2 on the preceeding figure.

On left, a Skaipiksa aerial photo from 1972 shows that the ridge in the centre of the image is covered with forest.

A low quality TM image from 1987 (not displayed) also records intact forest at this location.

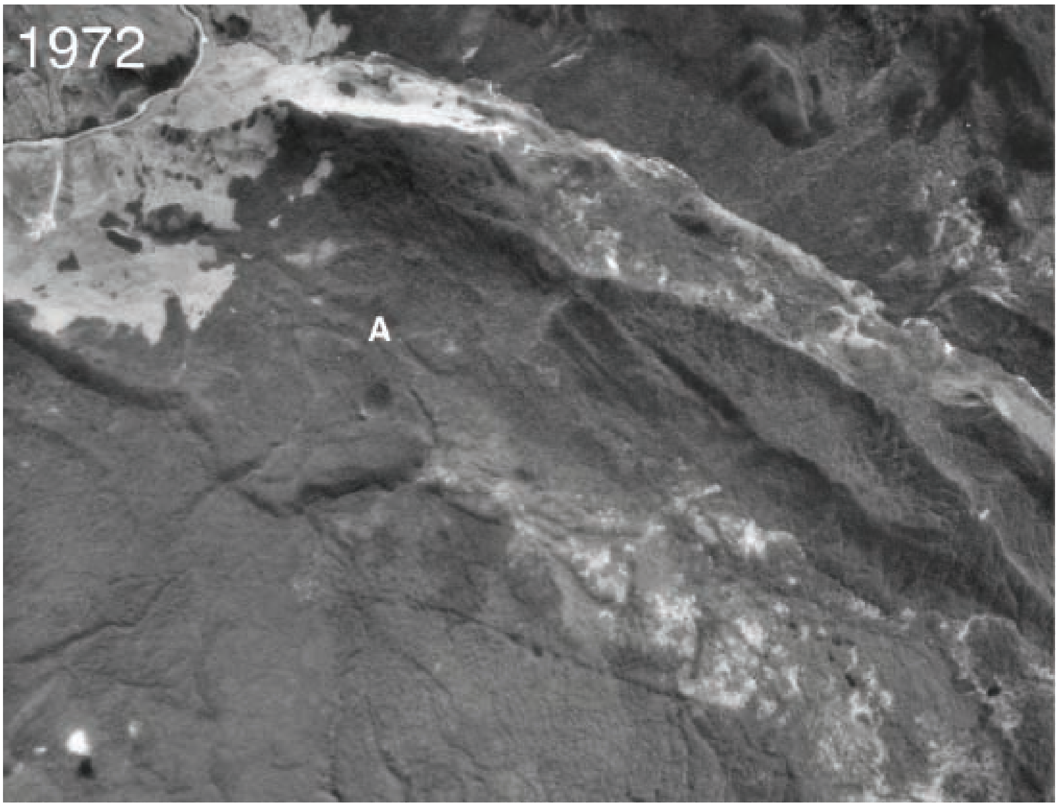
Below, on the 2002 image, a large area (approx. 2 x 1 km) of the ridge has been converted to grassland through burning (seen as red).

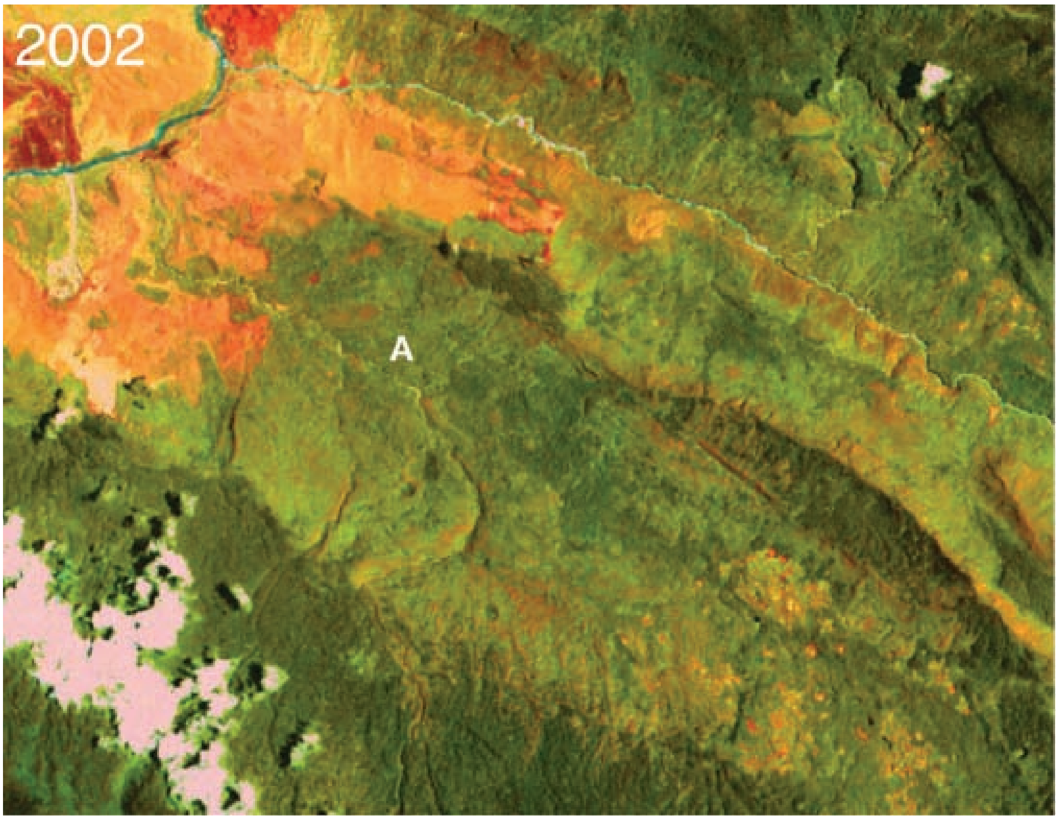
Fires have been recorded as hotspots in this area as recently as January 2007.

This strongly suggests that with regular firing it is possible to convert forest to grassland, and do so within a 15 year period.

These two images show the area demarcated as insert 3 on the preceeding figure (page 74). The upper image, a Skaipiksa aerial photo from 1972, shows that the area surrounding Location **A** is covered with intact forest. A low quality TM image from 1987 (not displayed) also records intact forest at this location.

The lower image from 2002 shows that scrub (light green) rather than forest (dark green) now surrounds location **A**. Interviews with landowners from this site clarified that fire spread from the Strickland Gorge in 1997/1998 and burned this area of forest. This forest may either eventually regenerate, or may be burned repeatedly until grassland becomes dominant. This suggests that burning of forest, at least initially, does not always result in its complete conversion to a stable grassland disclimax.





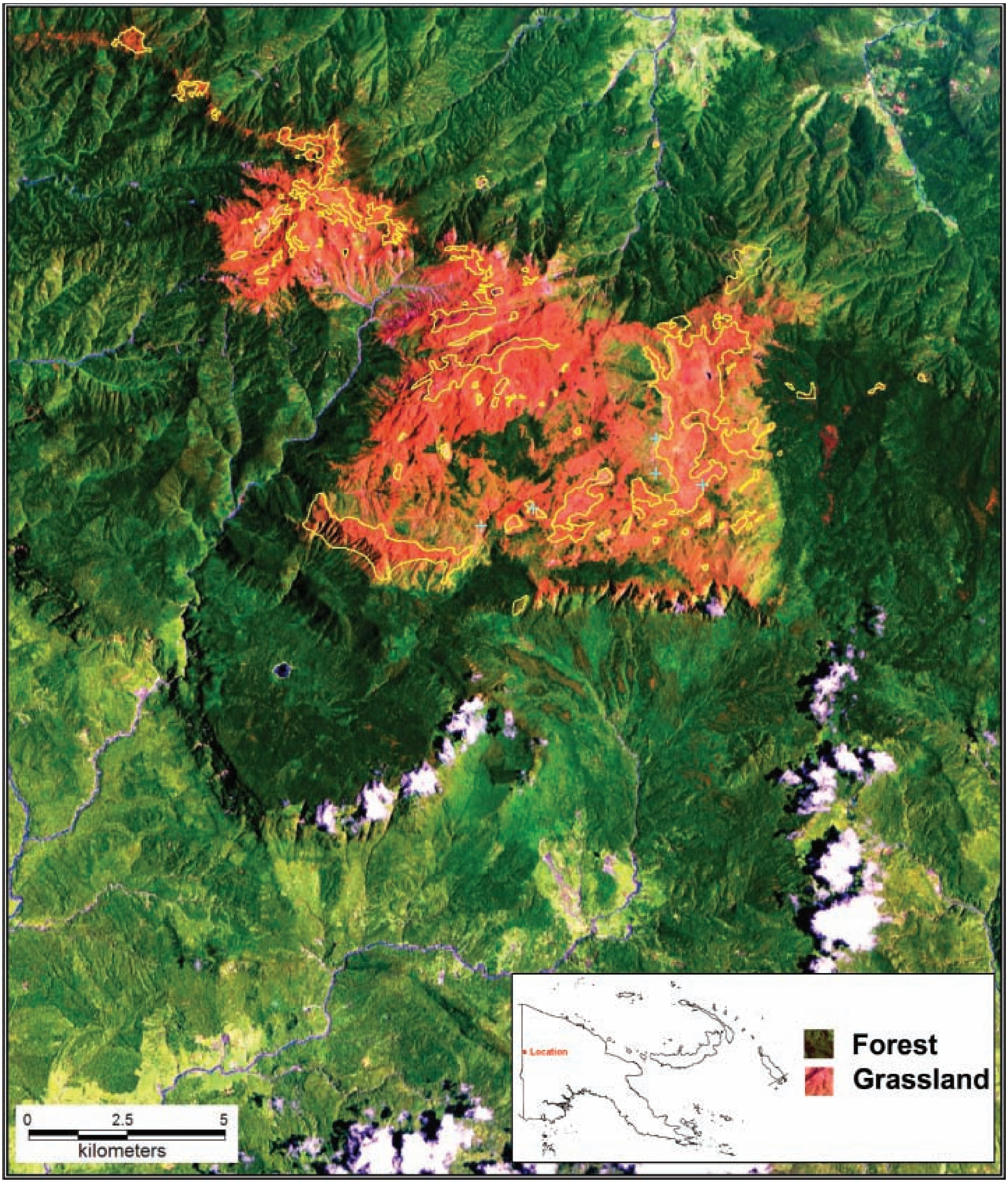


Figure 30: Deforestation on Mt Auriga and Mt Kusiwigasi (Scorpio) (4,015), Star Mountains, Western and West Sepik Provinces.

Above: a SPOT 4 image from 2002 is overlain by the 1972 forest/grassland boundaries (yellow lines). It can be seen that there has been a large area of forest loss on the upper slopes of this range. The Ok Tedi mine is located approximately 5km to the south of this image.

Fire locations from 2002-2004 are located in the figure with the symbol: + As can be seen, areas that were converted prior to 2002, have continued to be burned since.

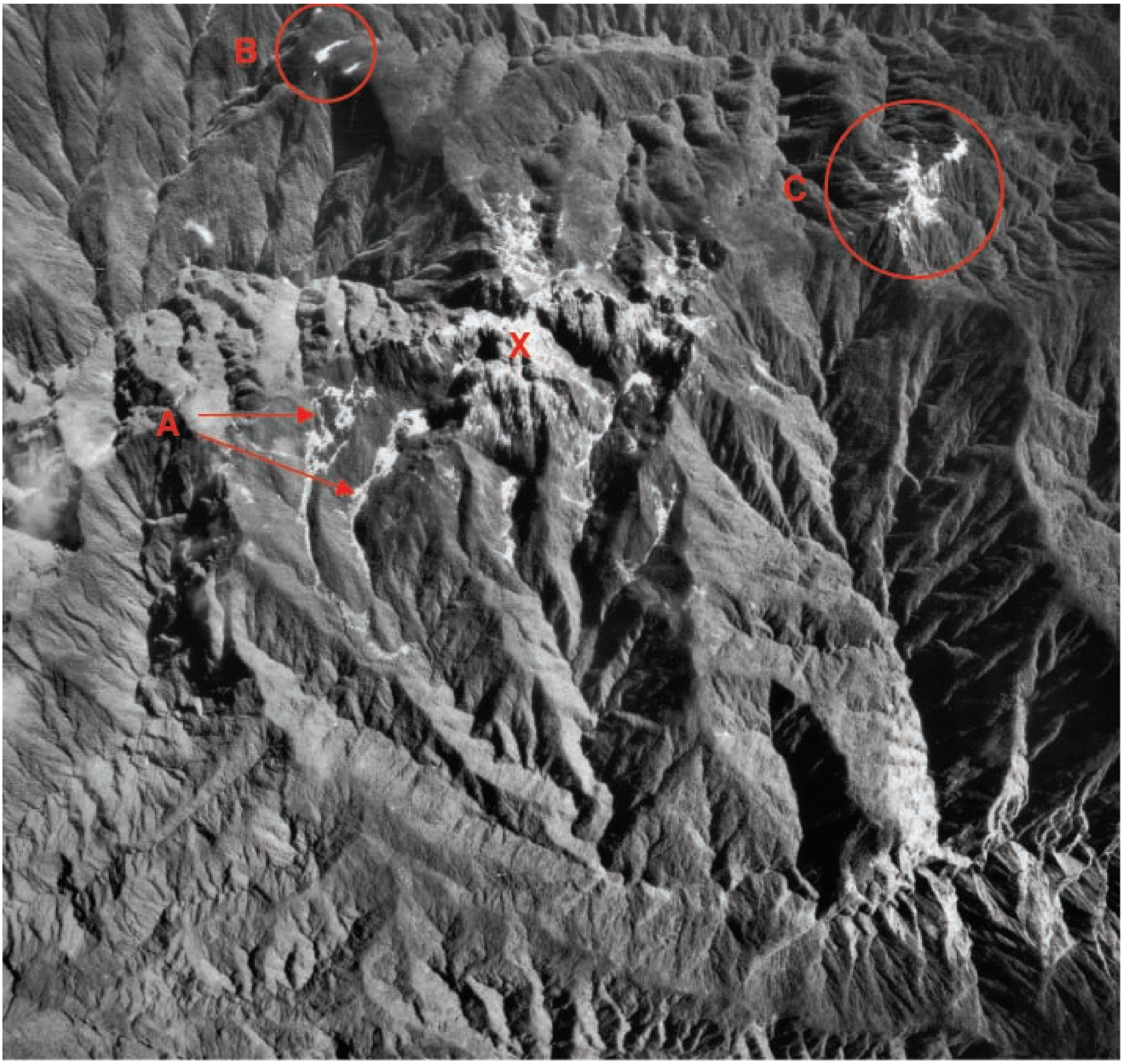
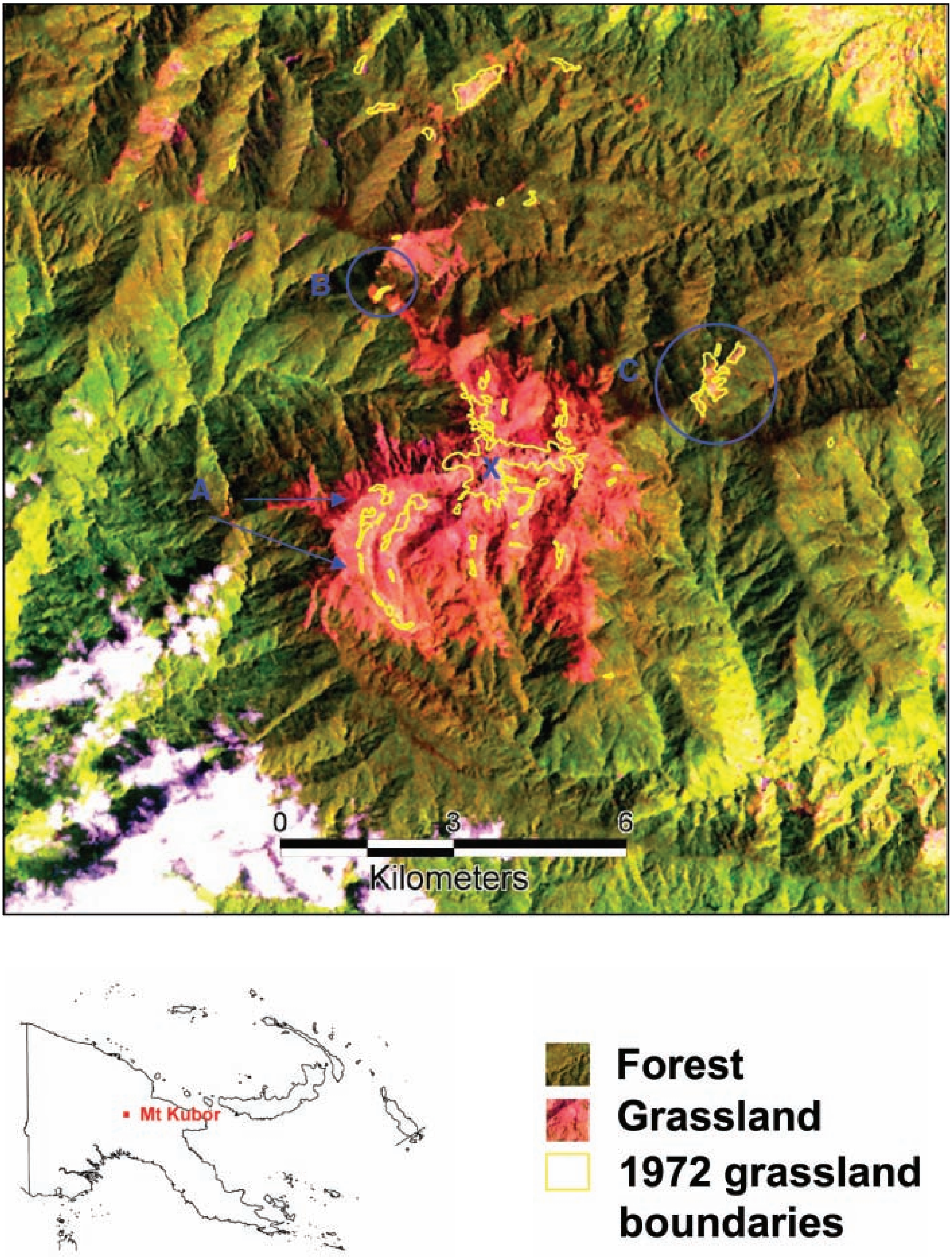


Figure 31: Deforestation on Mt Kubor (3,969 m), Western Highlands Province.

Above, a SkaiPiksa aerial photo shows the extent of forest cover and alpine grassland in 1972.

On the facing page, a 2002 Landsat ETM+ shows that areas of alpine grassland have, in some locations, expanded dramatically. The yellow lines overlying this image show the 1972 grassland boundaries that were derived from the 1972 Skaipiksa aerial photographs. A high degree of fidelity can be seen between these vectors and the above aerial image.

At location **A**, grassland, which was restricted to valley bottoms, has expanded dramatically. Around the summit (**X**) and location **B**, the area of grassland has also hugely expanded. In contrast at location **C**, there has been very little, if any expansion of grassland. This strongly suggests that the primary driver of forest loss has been fire, and not climatic factors, which should have applied equally to all of these locations.


B
C
X
A
0
3
6
Kilometers
Mt Kubor
Forest
Grassland
1972 grassland boundaries

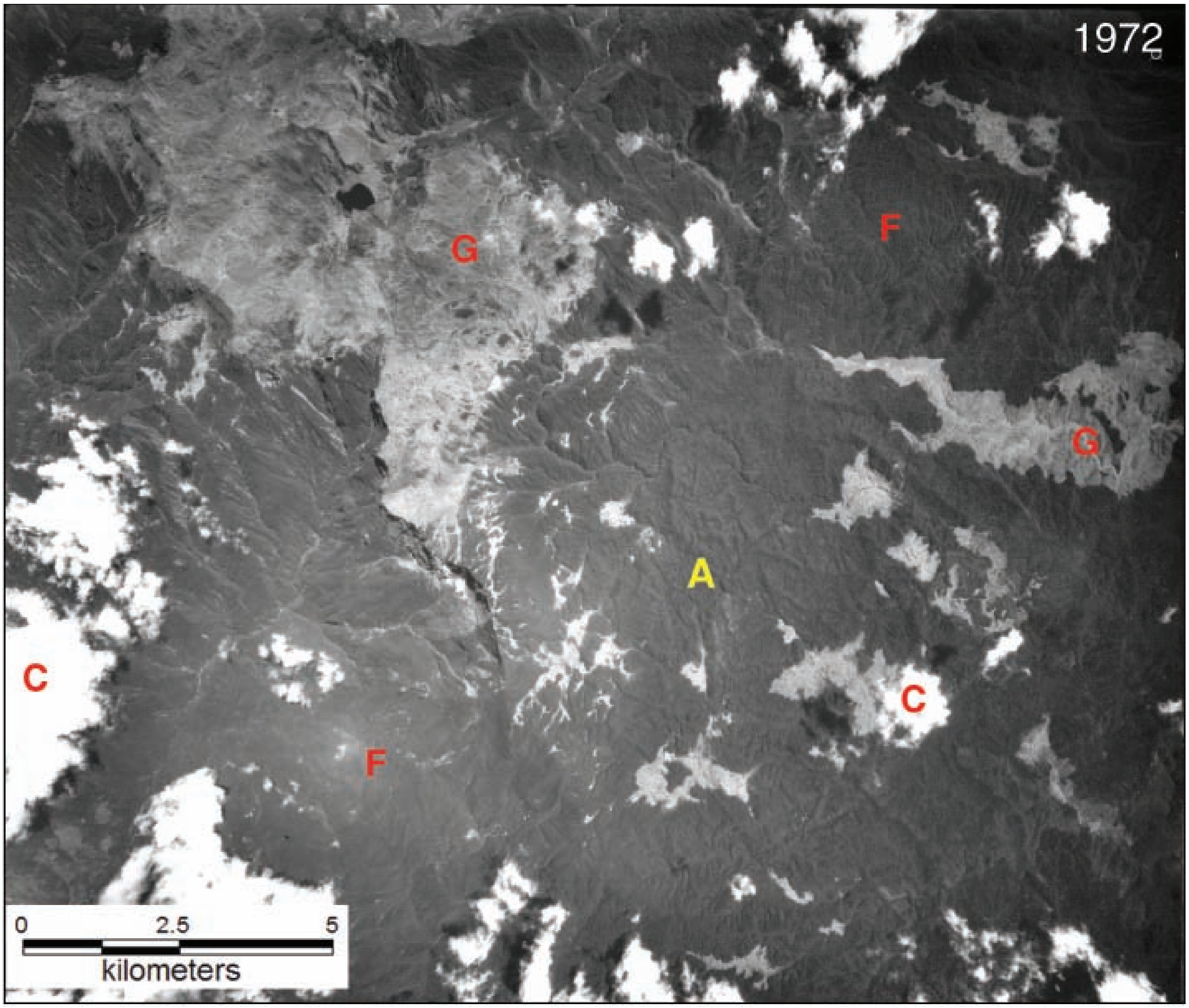
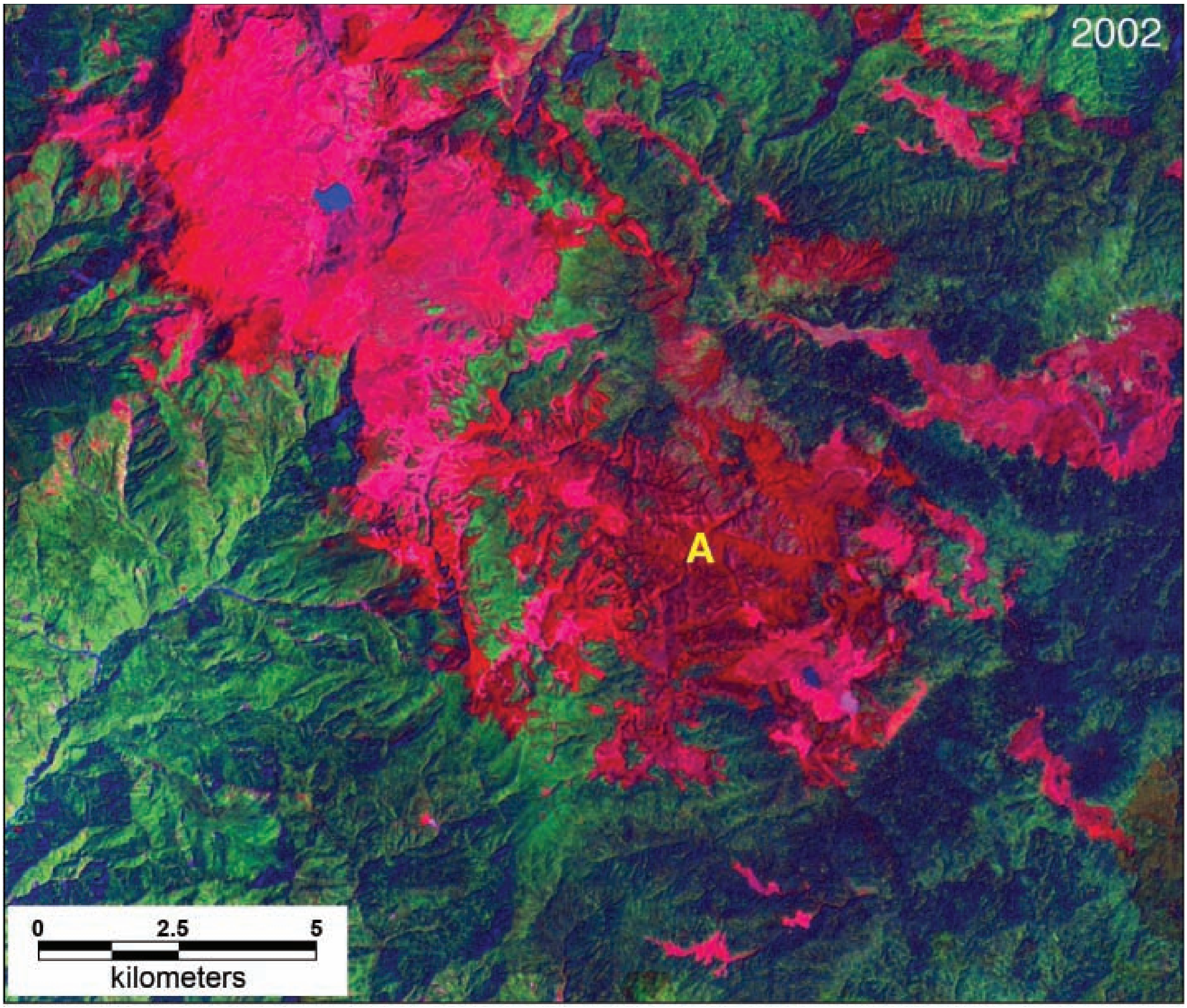


Figure 32: Deforestation on in the Saruwaget Ranges, Huon Peninsula, Morobe Province.

Above, a Skaipiksa aerial photo shows the extent of forest cover (**F**) and alpine grassland (**G**) in 1972. Numerous clouds also occur in the image (**C**). On the facing page, a 2002 Landsat ETM+ shows that areas of alpine grassland have expanded, centred on location **A**. This loss of montane forest occurred during fires in 1997/1998. A range of fire impact can be seen in this area.


2002
A
0
2.5
5
kilometers


Location


Forest
Grassland

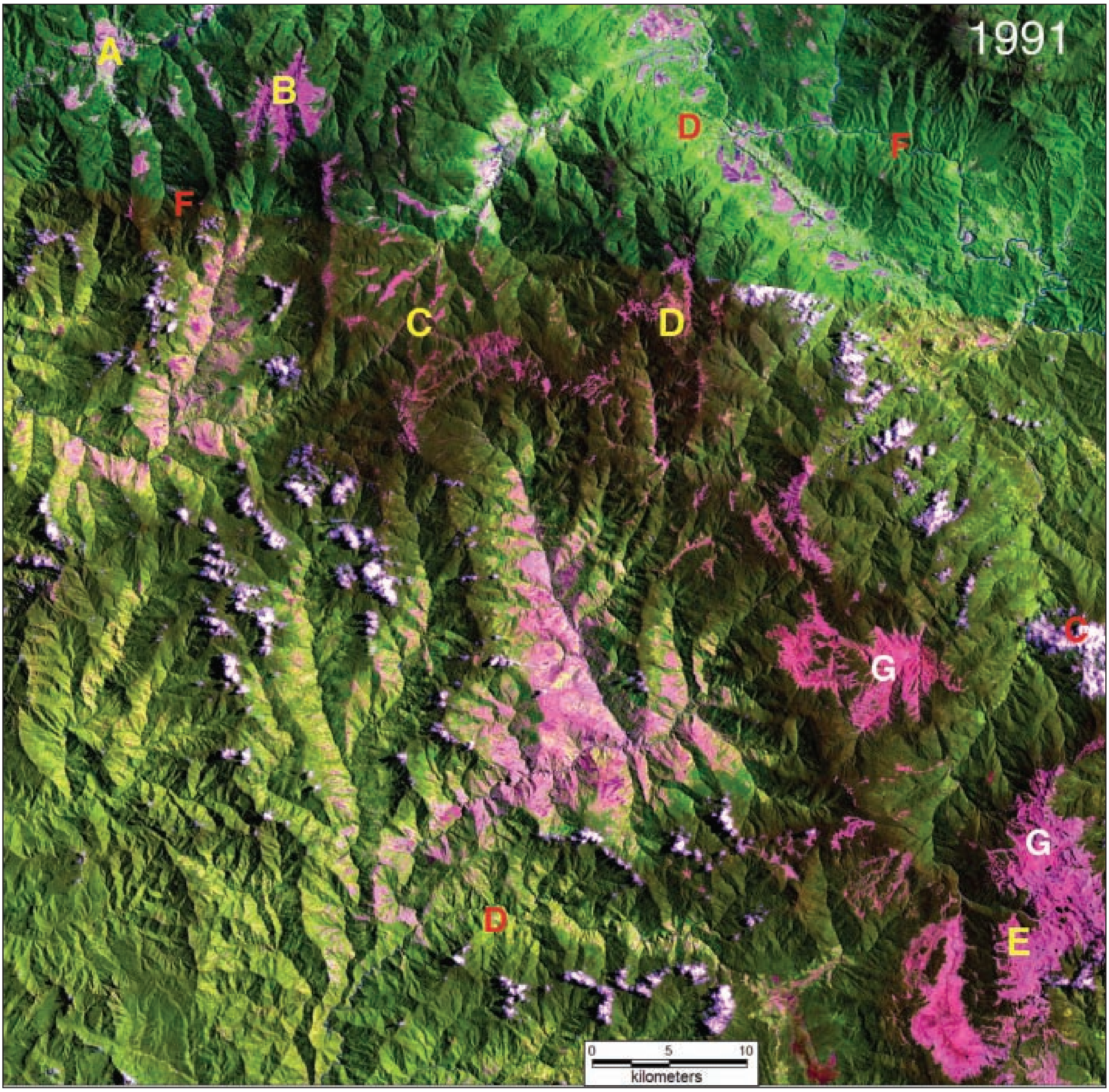
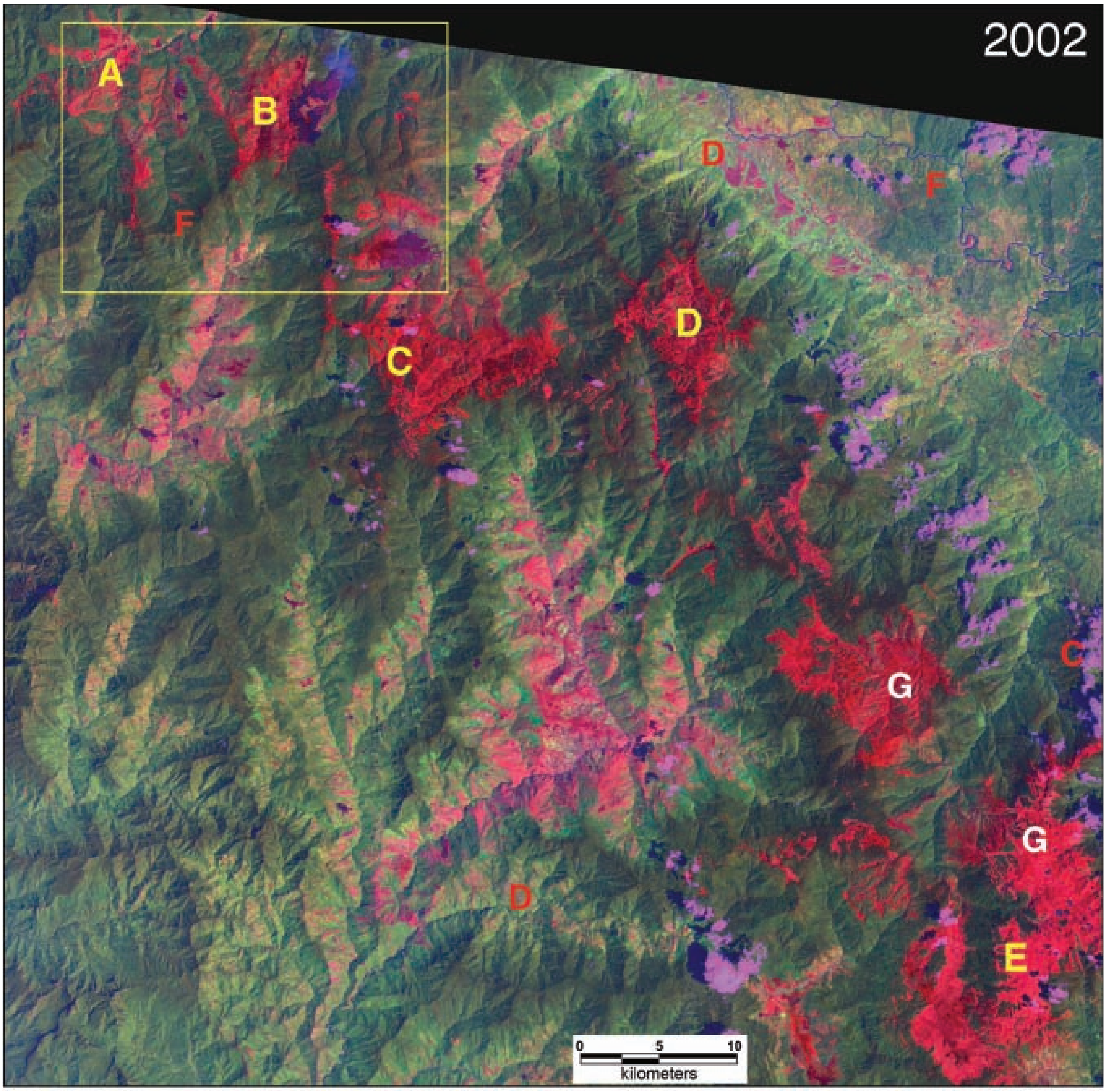


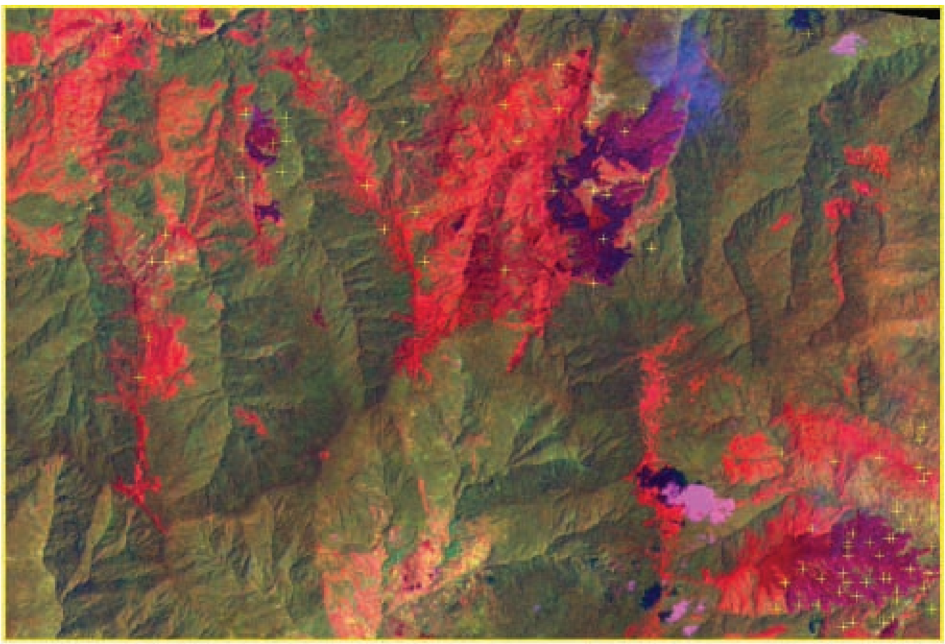
Figure 33: Deforestation in the northern Owen Stanley Ranges, Central, Morobe and Gulf Provinces.

Above, a Landsat TM image shows the extent of forest cover (F) and grassland (G) in 1991. Some clouds also occur in the image (C). Areas of Garden (D) can also be seen.

Comparison with the 2002 Landsat ETM+ on the facing page (with the same labels) shows that areas of alpine grassland have expanded, especially at locations A, B (Mt Chapman), C (Mt Dickson) and D (Mt Nelson). A fire can be seen close to location B. The insert (below right) shows the area around locations A and B, overlain by fire hotspot locations from the period 2004-2007. It is apparent that areas converted in the late 1990s have been burned regularly since then.



The image on right (insert from above) shows the location of recent fires with the symbol: +



3.4 Forest clearance for plantations

The study recorded that in 2002 there was a total area of 149,402 hectares under oil palm and rubber plantations in Papua New Guinea. Over 90% (135,843 ha) of this area was oil palm plantations, located mostly in West New Britain, Milne Bay, Oro and New Ireland.[5]

It was found that 93,101 ha or 62 % of the area currently under plantation was cleared during the study period. The majority of this clearance took place in West New Britain (58,467 ha) while other large areas were cleared in Milne Bay (12,234 ha), East New Britain (7,828 ha) and Oro provinces (67,71 ha).

In summary, clearing of forests for plantations was an important cause of change in some fertile lowland rainforests, especially in West New Britain where 3.2% of 1972 forest land was cleared, and in Milne Bay (1.1%). The extent of these areas is relatively small compared to the impacts of commercial logging and subsistence agricultural expansion on the national forest estate. Nevertheless, the figures are under-estimates of the impacts associated with oil palm developments as they do not include the impact of increased settlement and agriculture as a result of people migrating to and living around the plantations.

Two examples of forest loss associated with commercial agriculture are presented in Figures 35 and 36.

3.5 Mine-related forest clearance

The development of mines in PNG has had intense local impacts on the country's forests, land and waterways, but the study found that the area of forests affected directly has been small, totalling 0.2% of the 1972 forest area, with most of this occurring in Western Province (48,061 ha). However, this figure is almost certainly a significant under-estimation of the impacts of mining developments on PNG's forests, which are known to include increases in clearance for gardens in order to generate produce for use by the mines and their associated communities (Dambacher et al, 2007). For this reason an unknown portion of the deforestation associated with subsistence agriculture in this study should be attributed to mine-related clearance.

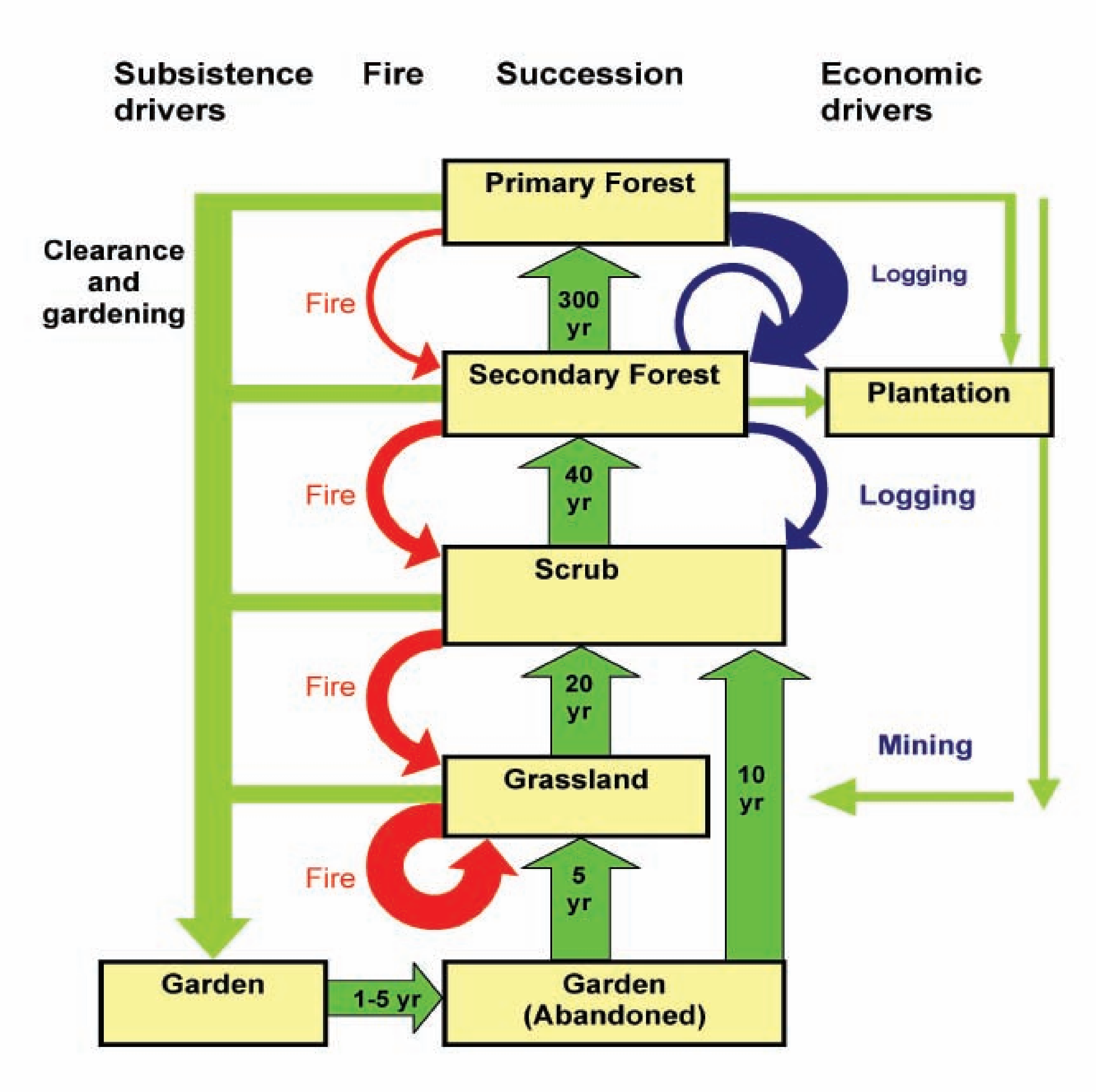
The study under-estimated the impact of Ok Tedi mine, where recent surveys suggest that dieback associated with tailings discharge is now affecting at least 150,000 hectares (Higgins, 2002). This under-estimate occurred because much of the area of dieback occurs in areas of Swamp Forest, where changes were not discernible by the techniques used in the study.

3.6 Summary

The preceding discussion of the main drivers of forest degradation and deforestation in PNG over the thirty years from 1972 to 2002 is summarised in Figure 34. This figure aims to identify potential successional states in land cover, the manner in which transitions between them occur and the drivers of these transitions. It suggests a dynamic of forest change driven by a combination of logging, agricultural clearance (both subsistence and commercial), fire, and to a minor extent, mining. It suggests that fires become more important and more severe in maintaining the process of succession the further the vegetation state is away from being Primary Forest. As discussed above, the fate of a logged forest depends upon several potential transitions, including conversion to some form of plantation, conversion to scrubland or grassland through burning, conversion into a gardening mosaic through cultivation or its regeneration over an extended period of time to an 'intact' primary forest state.

[5] *The areas of timber plantations in the Wau region of Morobe were not included in the calculations as most of these were already in existence in 1972, the baseline year for the present study.*

Figure 34: Hypothetical state transition model for PNG vegetation cover. The transition times are estimates only. The width of the red arrows indicates the frequency of fires. Note that 'abandoned' gardens will still yield perennial produce.



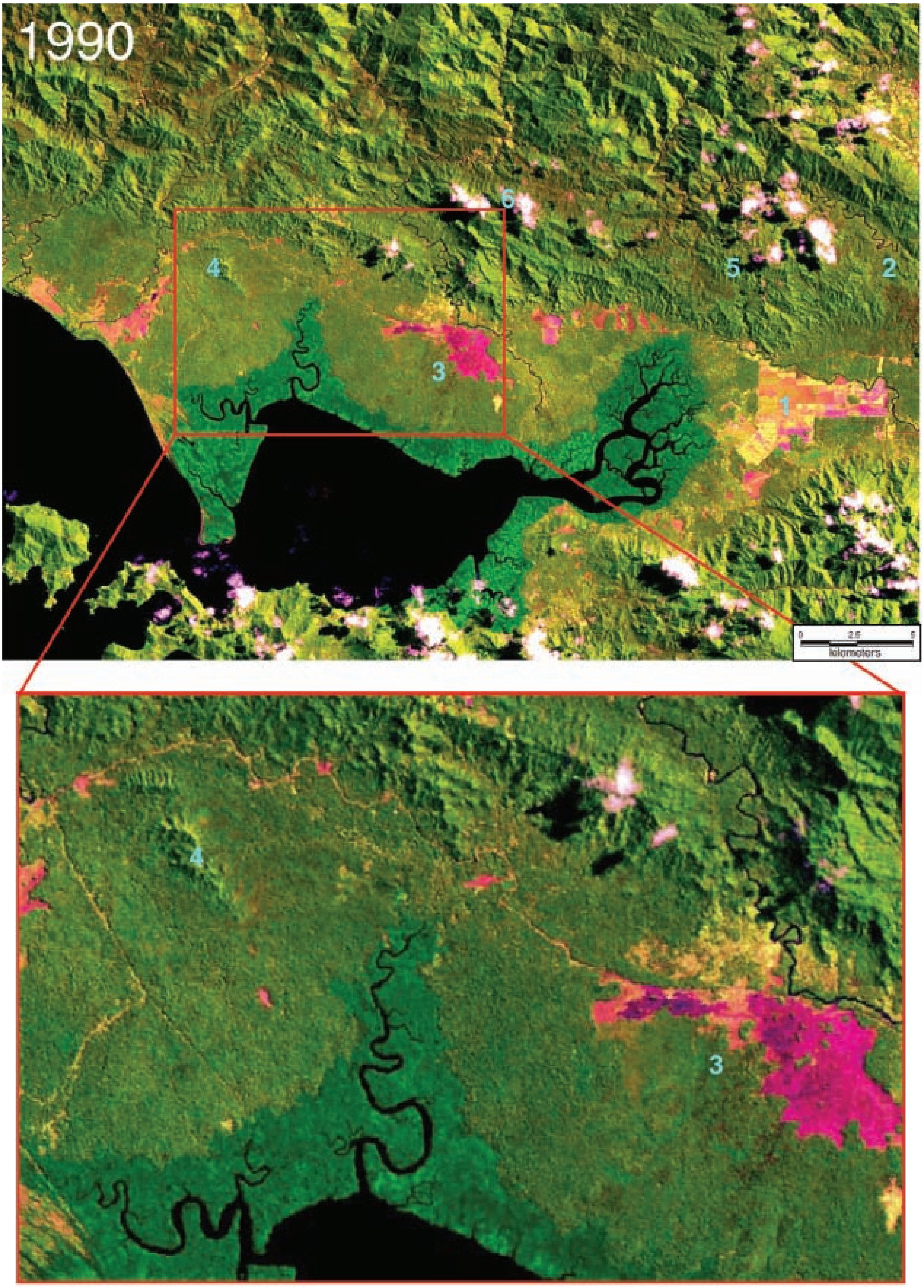
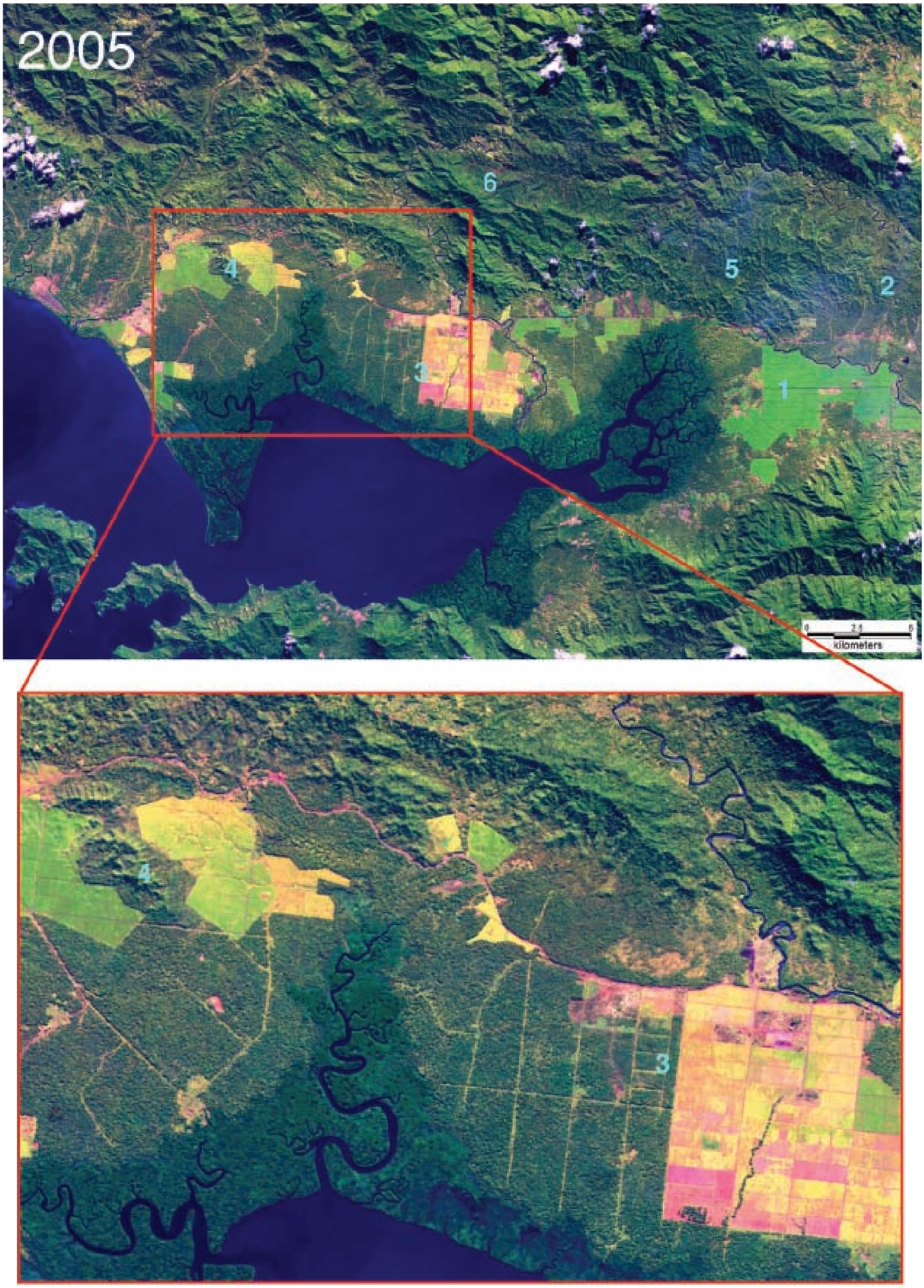
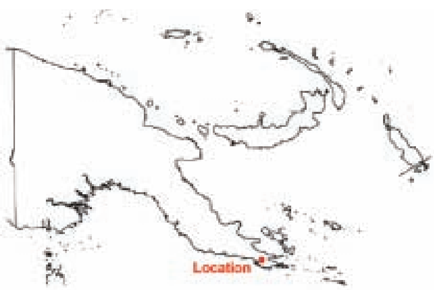


Figure 35: Deforestation in the Sagarai Gadaisu region of Milne Bay Province. This area has been systematically logged and in parts, converted to oil palm. Above, a Landsat TM image from 1990 shows the beginnings of oil palm clearance at location **1**, and logging commencing at location **2**. By 2005, the SPOT5 image on right shows further clearance for oil palm at locations **3** and **4** and logging through the mountains (particularly apparent at locations **5** and **6)**. This combination of logging then clearance for oil palm has occurred in Milne Bay, New Britain and New Ireland Provinces.


2005
6
4
5
2
3
1
0 2.5 5
kilometers
4
3


Location

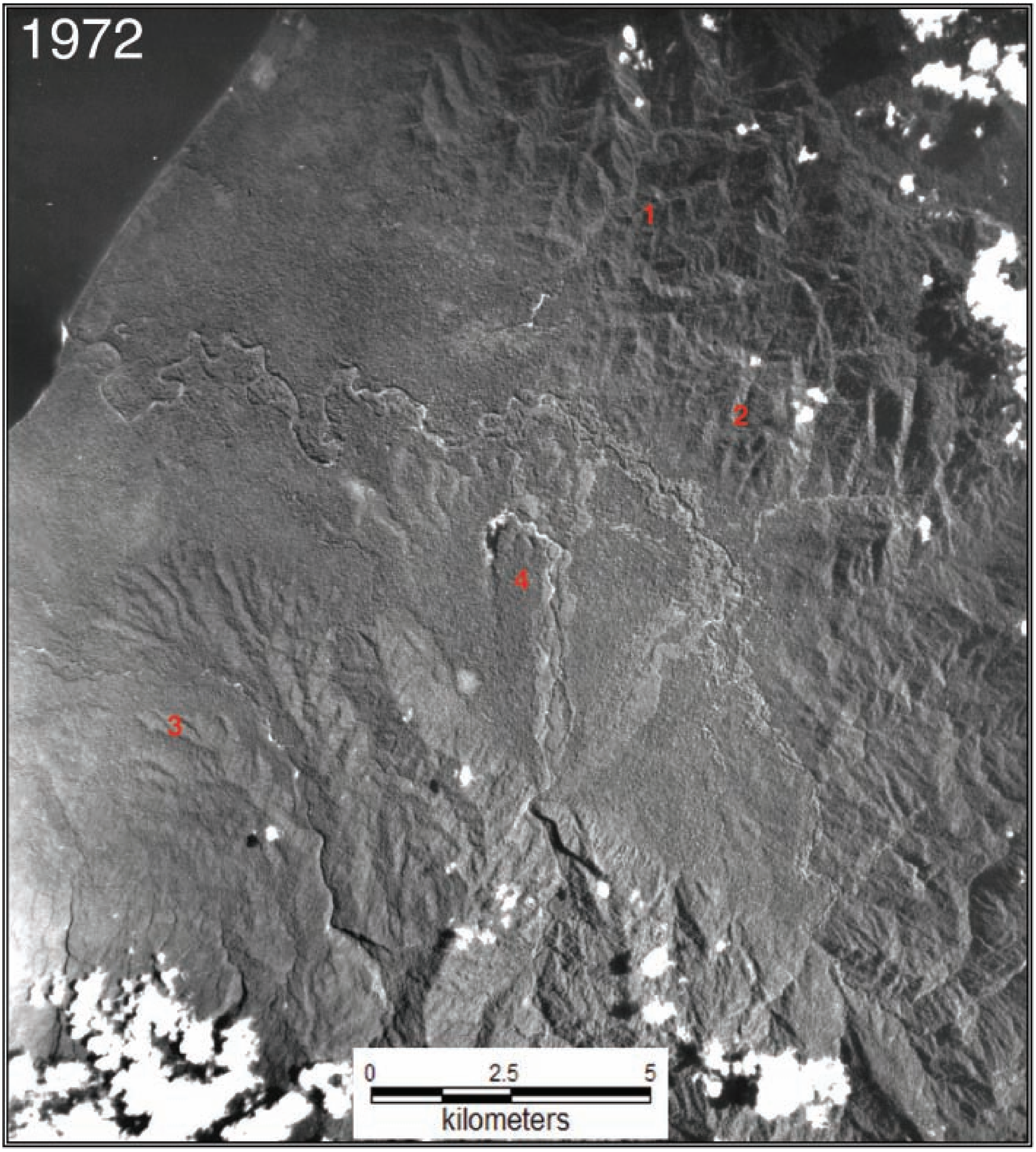
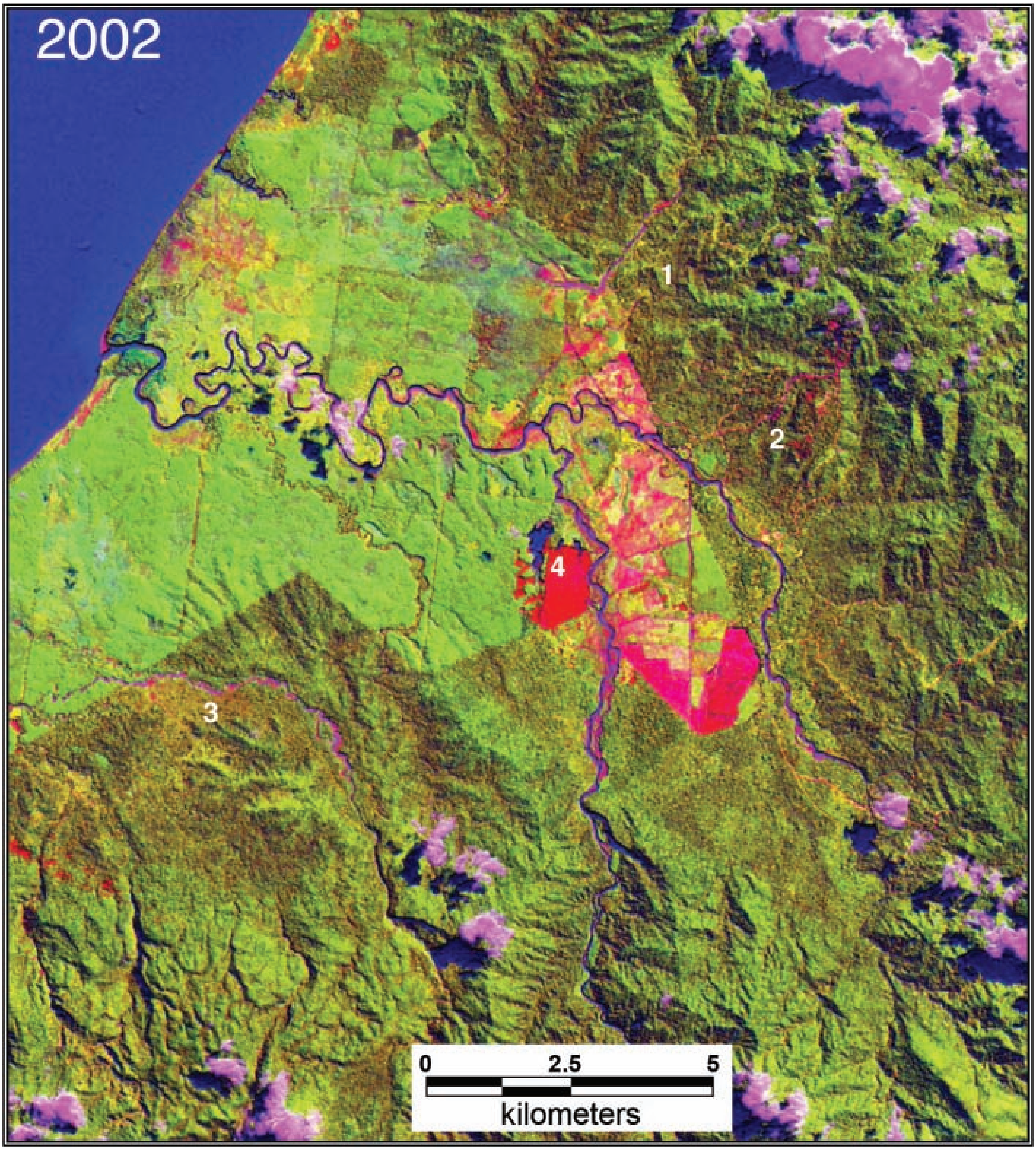


Figure 36: Deforestation in the Open Bay region of East New Britain.

Above: A Skaipiksa photograph from 1972 shows intact forest throughout this area.

On right: A Landsat ETM+ image from 2002 shows clearance throughout most of the lowlands and logging occurring at locations **1**, **2** and **3**. Intact primary forest has been replaced with plantations of *Eucalyptus deglupta*. A recently cleared and unplanted area is visible at location **4**.


2002
1
2
3
4
0
2.5
5
kilometers


Location

Chapter 4

Forest conservation efforts in Papua New Guinea

Over the past thirty years, a range of efforts have been made to protect the natural environment and biodiversity of Papua New Guinea, led or supported variously by government agencies, land-owners and local communities, scientists, non-government conservation and development organisations, and international donor agencies. Many of these initiatives have been concerned with forest conservation, recognising the fundamental and significant role of the country's extensive forests in maintaining the extraordinary biological diversity, the livelihoods, food production, raw materials, development opportunities, cultures and customs of Papua New Guineans, and the ecological services vital to the environmental health and wealth of the whole country.

Against this background, the present study reviewed the effectiveness of PNG's conservation efforts in protecting forest values. The study considered two broad and complementary approaches to forest conservation, namely forestry regulation, governing the extent and nature of practices exploiting forest resources; and site protection, designation of specific areas of forest habitat as reserves for ecologically benign or sustainable uses.

The clear conclusion from the analysis of forest change over the past thirty years is that the approach of forestry regulation has not produced useful outcomes for forest conservation. Logging is the main driver of forest change in PNG and has been carried out across all accessible parts of the country, with scant regard for its impacts on natural forest values. There is little or nothing in place to compensate for this extensive destruction, in the form of rational land-use planning, enforcement of low impact logging practices, controls over land erosion or land and water pollution, or the protection of particular vulnerable habitats, communities or species of plants or animals. Equally, there is little evidence of any effective reforestation or ecological restoration being carried out (ODI, 2006).

In PNG as in many other countries, forestry and nature conservation have tended to be pursued separately, with different groups of stakeholders and different supporting organisations and government agencies, working with little cooperation and often in opposition to one another. There have been some attempts by conservationists to facilitate sustainable forestry by promoting small-scale and low-impact logging, but these have had little ameliorating effect on the parameters of the commercial logging industry. The conventional strategy for conservationists has been to try to set aside discrete sites as reserves or protected areas. In common with the majority of other countries, Papua New Guinea has put in place a system of protected areas, although the proportion of land area protected is one of the lowest of any country in the world. Under this approach, relatively small areas are defined according to area boundaries, designated under a management prescription and given 'conservation status'. In addition, through the 1990s, with large grants available from international donors and international conservation groups, a series of larger-scale area-based conservation projects were started in different parts of PNG, in an attempt to counter the rapid escalation of commercial logging. Emphasis was placed on combining village and community development, income generation and biodiversity protection within a variety of Integrated Conservation & Development (ICAD) projects.

4.1 Forest conservation in ICAD projects

The general aim of an ICAD project is to provide local resource owners with an alternative to selling off their timber resources, by enabling them to develop their own resource-based livelihoods and achieve a sustainable balance between local economic development and resource conservation. It has proved difficult for ICAD projects in PNG to achieve and then sustain a satisfactory blend of conservation and development outcomes. The projects tended to become too complex and expensive, requiring numerous outside experts and substantial management and administrative infrastructure. Their complexity made them risky, and most appear to have not lived up to expectations. Some ICAD projects simply paid local people to not use a resource, sometimes in the form of a grant to develop a business venture, or as compensation. Most ICAD projects did not last for more than a few years.

On the other hand, some ICADs managed to get new protected areas and new small business enterprises started. Importantly, ICAD projects supported local participation, education programs, communal decision-making and planning processes that, if sustained, would be likely to deliver conservation and sustainable development in the long term.

In the present study an analysis was made of the outcomes for forest conservation and sustainable forestry of one of the longer running ICADs, the Kikori project supported by the international conservation group WWF and the oil companies developing the Kikori oil and gas fields, pipeline and export facility. The site is widely promoted as a model partnership between conservation and industry, successfully combining sustainable development with protection of some of the planet's most diverse lowland rainforest ecosystems (Burton, 2003). The extent of the Kikori ICAD highlights the high potential conservation value and the ambition of the ICAD approach: the project area of 2 million hectares is in marked contrast to the total of 1.29 million hectares enclosed within all 34 gazetted Wildlife Management Areas that make up PNG's protected areas system.

The results of the forest change analysis, summarised in Table A3 in Annex 1, indicate that the Kikori ICAD has not produced the promised conservation outcomes. There was a 10.3% reduction in the area of primary forest cover over the study period, attributable to the deforestation of 104,325 hectares and to logging-associated degradation of 76,979 hectares. These are comparable levels of change to those measured across the wider Southern Highlands (12.1%) and Gulf Provinces (19.5%), suggesting that ICAD designation conferred little protection on the Kikori forests. Of further concern is that virtually all of the accessible rainforest within the Kikori ICAD area, a total of 618,000 hectares, have been allocated to the logging industry. These findings illustrate once again the absence of any integrated land-use planning in Papua New Guinea – a process whereby an area demarcated for conservation (albeit alongside oil and gas extraction) could be quarantined from other forms of exploitation. While local people have a high degree of influence over local land-use decisions, the determination of regional development trajectories and within that, the fate of the forests, are ultimately decided by the national government.

Forest conservation in PNG's gazetted protected areas

Nature reserves or protected areas have been formally designated in Papua New Guinea under the National Parks Act or the Fauna (Protection & Control) Act. To date, Wildlife Management Areas (WMAs), established under the latter Act, have been the only type of protected area that has proved to be widely relevant to Papua New Guinea (Hunnam, 1992). This study made an assessment of the effectiveness of PNG's WMAs and National Parks (NPs) in protecting the forests that they enclose.

The WMA is custom-made for PNG, recognising that virtually all land, forests, plants and wildlife are held under customary tenure, in effect owned by and the responsibility of local landowners and clan groups. The WMA allows the landowners of a local area to formalise their controls over its natural resources in order to manage hunting, fishing and harvesting of other resources, within the framework of national law. Land ownership is affirmed and the WMA's local managers are able to seek support from the responsible national government agency, the Department of Environment and Conservation (DEC).

The current national system comprises a total of 34 terrestrial WMAs and NPs that have been formally gazetted, covering just 1.29 million hectares or 2.8% of PNG's total land area. As these low numbers indicate, establishment of protected areas has not been a smooth process. Over a third of existing protected areas were gazetted in the first four years of Independence (1975-1979). In the subsequent 23 years, only 15 more were declared. A comprehensive review in 1992 found that, even without any promotion or publicity of the scheme, a backlog had accumulated of 120 proposals from landowners for assistance from DEC to establish WMAs (Hunnam, 1992). Nevertheless, in the past 13 years, only 7 new WMAs have been established and all have come about through major efforts by non-government organisations, with little support from government. It is also relevant to note that the national government recently imposed a moratorium on the ratification of new protected areas in order to negate the potential for conflict with the allocation of potential logging areas to the timber industry, under the government's 'export driven' economic policy.

Analysis of forest protection and change within WMAs and NPs

This study recorded that in 2002, the 34 designated protected areas encompassed a total of 541,928 hectares of rainforest, 54,332 ha of swamp forest and 8,892 hectares of mangroves. These areas represent just 1.9% of the country's total 2002 rainforest estate, 1.6% of the swamp forest and 1.5% of PNG's mangrove forest. The very small proportions represented in WMAs indicate that the current national system of conservation areas is inadequate as a forest protection strategy, a finding consistent with a previous assessment of protected areas in PNG which found that most WMAs were too small to maintain sensitive species or natural processes (Chatterton et al, 2006).

The study also found that almost half of PNG's forest types are not represented in the current WMAs. The current sites contain almost no upper montane forests, despite their conservation significance, and there is under-representation of forests of the East Papua Islands, South East Papua–Oro and the Owen Stanley regions. Only 0.07% of 2002 forested area in the South East Papua-Oro region is contained in WMAs, only 0.03% of forested area in the Owen Stanley region, and no forested area in the East Papua Islands.

Further confirmation of the inadequacy of the WMA system as a means of protecting forests in PNG is provided by the levels of deforestation and forest degradation that have occurred within their boundaries. Over the 30-year study period, a total of 38,926 hectares of forests within WMAs were cleared, mostly by subsistence activities, and an additional 11,951 hectares of forests were degraded by logging. The study found that overall, the areas of intact forest within WMAs were reduced by 8.8%

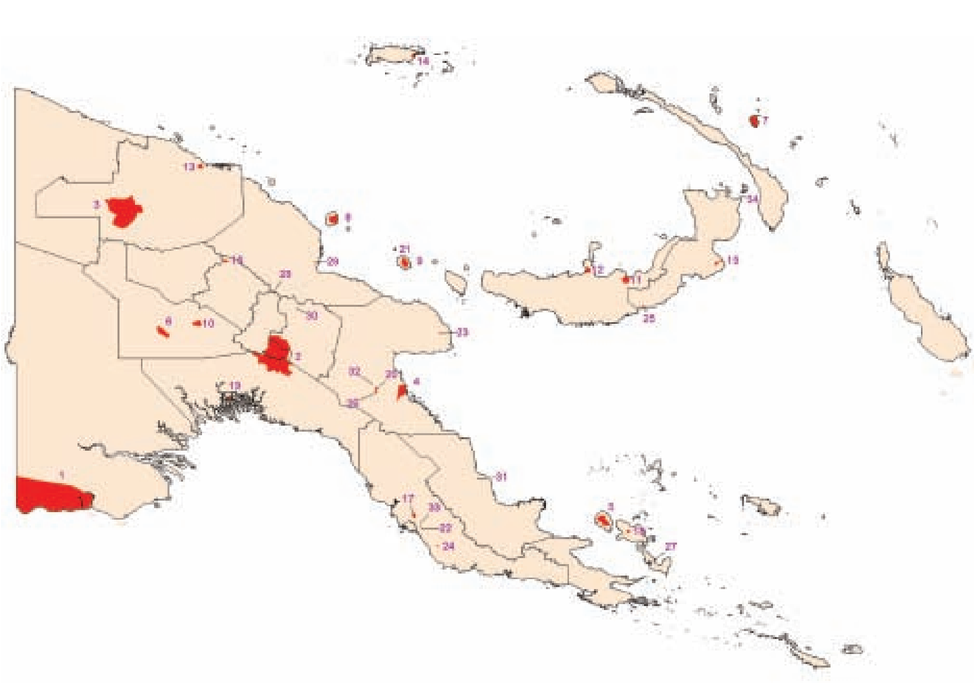
over the study period. While the extent of this change is considerably lower than the country average of approximately 24%, there was wide variation in the amount of forest loss in individual WMAs, ranging from zero to 100%. An additional 7.0% of forests located within WMAs have been earmarked for logging. The areas of forest types and extents of forest change are presented in Table 3 in Annex 1.

An important factor in this analysis is that the majority of forest in the WMA system is enclosed in two of the most recently-designated WMAs – Hunstein Range in East Sepik Province (160,850 hectares of rainforest in 2002; gazetted in 1998) and Crater Mountain WMA, which straddles Gulf and East Highlands Provinces (255,306 hectares of rainforest in 2002; gazetted in 1992). Together they account for 77% of all forest within all WMAs. The forests in these two WMAs have suffered relatively little loss (2% in Hunstein and 3% in Crater Mountain) over the thirty year study period. Although it is likely that these losses were caused by subsistence clearing carried out since the formal gazettal of the protected areas, it is apparent that these two areas have suffered relatively little damage primarily because of their physical inaccessibility to mechanized logging operations, and the low density of the local populations.

If the other 32 PAs are considered separately from Hunstein and Crater Mountain, then the results of the change analysis present a radically different picture of the effect of protected area designation. In the other 32 PAs, 25.5% of the 1972 forest area had been cleared or degraded by 2002, changes affecting 39,053 hectares of forest overall. This suggests strongly that for the majority of PNG's protected areas, there is no discernible difference in the rates of forest loss on either side of their boundaries.

The results of this analysis strongly suggest that the current system of protected areas is ineffective on a number of levels. The WMAs contain only a very small proportion of PNG's forest estate, and this area is disproportionately located in the lower montane forest zone; a zone that has been least affected by logging and subsistence clearance. The WMA network has not been designated with the rationale of protecting representative examples of forest types in the various bioclimatic and bioregional zones. Furthermore, outside of the Crater and Hunstein WMAs, the other 32 WMAs are experiencing clearance and degradation at rates comparable with the rest of the country. Given that they are generally not benefiting from any external assistance, there is little reason to expect any difference. The fact that large areas of some WMAs have been logged and much of their unlogged area has been allocated to the logging industry, only emphasises that the management of protected areas has not been taken seriously by the Government of PNG.

Figure 37: The location of designated WMAs and National Parks in PNG.



1 = Tonda WMA; 2 = Crater Mt WMA; 3 = Hunstein WMA; 4 = Kamiali WMA; 5 = Oia Mada Wara WMA; 6 = Lake Kutubu WMA; 7 = Lihir WMA; 8 = Bagiai WMA; 9 = Ranba WMA; 10 = Siwi Utame WMA; 11 = Poliki WMA; 12 = Garu WMA; 13 = Mojirau WMA; 14 = Ndrolowa WMA; 15 = Klampun WMA; 16 = Jimi Valley WMA; 17 = Iomare WMA; 18 = Lake Lavu WMA; 19 = Neiru WMA; 20 = McAdams NP; 21 = Crown Island WMA; 22 = Varirata NP; 23 = Mt. Nuserang WMA; 24 = Zo-Iomage WMA; 25 = Tavalo WMA; 26 = Mt Kaindi WMA; 27 = Sawataetae WMA; 28 = Mt Wilhelm NP; 29 = Balek WMA; 30 = Mt. Gahvisuka WMA; 31 = Hombareta WMA; 32 = Mt Susu WMA; 33 = Namanatabu WMA; 34 = Nanuk WMA

Chapter 5

Outlook for Papua New Guinea's forests

The analysis of forest change over thirty years confirms that the diverse old-growth rainforests that dominate the rugged landscape of Papua New Guinea are being destroyed rapidly. It will not be long – perhaps in the lifetimes of the country's current leaders and policy-makers – before the ecology of large portions of the country has been degraded permanently, with major consequences not only for terrestrial and marine biodiversity and timber and non-timber production, but also for the livelihoods, health and development prospects of large numbers of Papua New Guineans.

The changes being wrought by the degradation and clearance of the nation's forests will drastically reduce future options for the country's economy and its capacity to maintain a healthy and content society. In an era when the majority of nations are striving to regain lifestyles, resource use practices and economic activities that adhere to the principles of sustainable development, PNG has watched over the wholesale destruction of its natural capital, with little or no benefit accruing, even short-term, for the great majority of its people.

This study establishes that PNG's logging industry and food production from swidden agriculture are both utilising forest resources at unsustainable rates. In any local forest area being logged carelessly or cleared for gardens, there is a 'point of no return' beyond which the chances of the forest regenerating and recovering approach zero. The study indicates that in many parts of Papua New Guinea, in the coastal lowlands accessible to loggers, and the montane forests of the densely-populated Highlands, this 'tipping point' has been reached or passed, and the forest loss or conversion is essentially irreversible.

In summary, in PNG today a serious chain of events is unravelling as a consequence of deforestation and forest degradation. The longer the current forest management regime continues, the more difficult it will become to introduce changes towards ecological sustainability and to avert local or more widespread collapse. The issues of changes occurring in the parameters of subsistence land use in the face of a continued population expansion require careful consideration.

5.1 National visions

It is apparent from the analysis of the state of Papua New Guinea's forested landscape and of conservation efforts over thirty years of being a self-governing nation, that there is no adequate system in place for ensuring that land and forest development are sustainable and the country's unique natural values are protected. There is a clear need to find a new direction for national development, one that will meet the provisions in the National Constitution and conserve the natural resources of the country for present and future generations.

Despite the fundamental significance of PNG's forests for the country's ecology and the futures of the great majority of its citizens, there is no coherent leadership or coordination of efforts to protect forest and land values and secure their sustainable development. For many, the integrity of its diverse forests, ecology, tribal cultures and endemic flora and fauna make conservation an imperative. As ecological knowledge has improved and been shared over recent decades, the essential grounds for conservation have been increasingly recognised internationally and locally. However, others see different end-points for Papua New Guinea. A conceivable alternative scenario is of a greatly increased population, mostly of urban dwellers, engaged in manufacturing and service industries, in a de-forested and drained landscape of intensive agriculture, depleted quarries, degraded rivers and socially and economically impoverished rural communities. In these circumstances, the integrity and diversity of the country's unique ecology, biota and cultures would be destroyed.

There has been little movement over the past decades towards a vision that might be shared between the major stakeholders involved – governments, landowners, resource developers, conservationists and local communities. Those seeking or advocating conservation and a sustainable future need to be much clearer about their vision and objectives: to what extent should natural values be conserved and at what costs to development? What limits would be imposed on logging, forest clearing, plantation development, quarrying and mining minerals? What resource-based industries would best support the rapidly-increasing rural population and their economic and social development? For their part, resource developers appear unwilling to accept limits to access to resources. All parts of the country have been considered open to exploitation, even within gazetted nature reserves. Yet there appears to be little regard for the principles of equitable development or benefit sharing. Governments have failed to find and promote, much less enforce a balance between conservation and development. It is questionable that the increased revenue from natural resource extraction has produced equivalent increases in health and education services and infrastructure development. If it has not, what measures can be put in place to guarantee that further natural resource extraction will result in positive outcomes for the majority of New Guineans?

Papua New Guinea's forests – vanishing opportunities

- ❖ A unique portion of the Earth's most diverse and valuable forest habitats and biodiversity is being destroyed.
- ❖ The country's natural reservoirs of forest carbon are being depleted and CO_2 emissions are rising as logging, gardens and fire contribute to forest degradation and clearance.
- ❖ Old-growth forests with very high diversity, including high proportions of endemic species, are being degraded through logging to scrub and converted to grassland or monoculture plantations.
- ❖ Forest clearing and burning for swidden agriculture and subsistence food production are reaching a 'ceiling' in the most densely-populated areas of the country, indicating problems for further expansion of agricultural production.
- ❖ Forest is being repeatedly logged and degraded, with decreasing likelihood of regeneration. Deforested land is drying out, burning more frequently and converting to unproductive and species-poor grasslands.
- ❖ There is virtually no restoration of damaged land nor rehabilitation or replanting of forest.

Forest conservation futures

From the present study and others, there are clear lessons available within PNG for the effective long-term management of natural resource uses, applicable to forestry but also to agriculture and fisheries, and for the purposes of biodiversity conservation and economic development that is environmentally sustainable and socially equitable. Papua New Guinea needs to implement strategies for conservation and sustainable development that work for its people and their cultures.

Clearly, current forest conservation efforts are not adequate or effective. Forestry is unregulated, unsound and wasteful strip-mining of an invaluable national resource. Conservationists are driven too much by the conventional approach of Protected Areas, and a narrow determination to safeguard 'the best bits'.

The past thirty years have shown that management of natural resources for conservation and development has to be comprehensive and integrated if it is to achieve its multiple balanced aims effectively in the long term. Site-based conservation of nature is an important strategy that remains to be properly implemented and supported in PNG. Strengthening the WMA system and then providing appropriate support for the many hundreds of applications from groups of customary landowners could be done immediately, easily and at modest cost, and should be given the highest priority. Despite the system's neglect, the WMA remains a suitable starting point for creating local resource management areas dedicated to multiple sustainable uses. Such a scheme could be developed country-wide, readily and rapidly, to create an effective system that is applicable and accessible to virtually all landowner groups across the country.

This approach would be more appropriate for Papua New Guineans and more effective in conserving the country's biological diversity than the current tendency of conservation organisations to seek isolated, 'pristine, 'wilderness' sites and thereby avoid conflicts with logging or agricultural interests[6]. People and their welfare are intrinsic to conservation activities, nowhere more so than in Papua New Guinea and their involvement and assistance will be crucial in working towards a reasonable ecologically-grounded future.

Integrated land and forest management, catchment by catchment

It is doubtful that the notion of 'setting aside' 10% or 20% of the land area for conservation is a useful or desirable objective for PNG, despite its appeal to biodiversity collectors and indeed industrial developers. The outcome of the past thirty years of conservation and development efforts suggest that an <u>inverse</u> target may be more meaningful and appropriate: to zone 90% of the land for conservation, in the sense of judicious and integrated use of the country's natural resources. Inverse zoning would indicate that with additional safeguards the country might be able to afford to degrade up to 10% of its terrestrial ecosystems without reducing the natural values and ecosystem functions of the remaining majority. The principal value of such a target would be to stress that much more attention needs to be given to the management of resource uses – for forestry, agriculture, mining, fishing, urban settlements and infrastructure – to ensure that their impacts on natural values are reasonable and acceptable. The inability to adequately prescribe and build institutional capacity to govern ecologically sustainable development and integrated use of natural resources is the major area in which conservationists and the PNG Government have failed.

A comprehensive land-use and development plan governing the management of natural resources is long overdue in Papua New Guinea. Mechanisms should be developed for each forested catchment

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[6] *This approach was well exemplified by the BioRap Toolbox – a National Biodiversity Assessment and Conservation area planning project attempted to identify initial sites for Biodiversity Protected Areas that would cover 10% of the land area of PNG, while maximising the quantum of biodiversity that would be protected (Nix et al, 2002). The study however imposed bias in the target algorithms to minimise conflict with resource extraction industries by deliberately excluding areas of high timber volume or high soil fertility.*

from montane zone to the coast to be considered as a functional whole. It is vital that that forestry and agricultural developments are soundly regulated within a management regime that protects the catchment's basic natural ecosystem processes. Importantly, within each catchment management area, a revitalised WMA network would form the essential building blocks for local ownership and collaborative land and forest management.

In conclusion, the following recommendations are made to develop capacity and strengthen land and forest management in PNG:

Forestry

- ❖ Current logging industry activities need to be either closed or comprehensively reformed before being allowed to proceed under a revised regulatory framework that properly addresses sustainability.
- ❖ Planned new large-scale logging projects should be scrapped.
- ❖ The management of post-logging areas needs urgent intervention by the government of PNG and development partners. There needs to be a major effort made in forest rehabilitation to allow regeneration over current logged areas over a long period of time. The GoPNG should consider outsourcing reafforestation activities and consider the provision of assistance to post-logging communities.
- ❖ New forestry programs should be developed as small-scale, locally-owned and managed operations adhering to strict rules over ecological impact and sustainability and delivery of equitable social and economic development.
- ❖ The designation of forestry areas should be made in recourse to an integrated national forest management plan that incorporates values of extant forests beyond their timber value.

Integrated catchment management of land and forests

- ❖ Integrated land and forest planning and management in each major river catchment should be established to support multiple sustainable uses of natural resources – for both conservation and local livelihoods based on production of food, timber and non-timber forest products.
- ❖ The benefits from forest and land conservation and development activities as well as the responsibilities for ensuring ecological sustainability and conservation need to be shared equitably by the communities in each locality.

Support for local landowners and community initiatives

- ❖ Rural extension and support services need to be comprehensively reformed and strengthened, with a renewed focus on facilitating agriculture, forestry and land development initiatives and practices that are socially beneficial and ecologically sustainable.
- ❖ Conservation and development initiatives must recognise and be organised around customary tenure, knowledge and practices.
- ❖ A strengthened WMA system should be used to extend registration of communal resource rights as a national system, and to institute local community-based resource management within a supportive national legal and technical advisory framework.

Natural resource governance for sustainable development and biodiversity conservation

- ❖ Efforts to conserve biodiversity and natural resources need to become core business of government and customary landowners working in partnership, not the preserve of the 'international community'.
- ❖ The currently separate national governance regimes for forestry, fisheries, land and river management and conservation should be integrated into a streamlined Natural Resource Management agency, with a strengthened mandate to manage the protection, use and development of the natural resources of PNG so that they form the ecologically-sustainable foundation for socially-equitable development across the country.

Annex 1 – Data tables

Province	Zone	1972 Primary Forest Area (ha)	2002 Forest Area			1972-2002 Change									
						DF							DG	DF & DG
			Total (ha)	Primary (ha)	Degraded (ha) (%)*	NF (%)					F (%)	Tot.(%)	F(%)	Tot. (%)
						Sub.	Fire	Plant.	Min.	Tot.				
Southern Highlands	H	2,126,200	1,877,043	1,869,724	7,319 (0.39%)	10.62	0.89	0	0	11.51	0.21	11.72	0.34	12.06
Enga	H	929,318	807,871	807,871	0	12.91	0.05	0	0.10	13.07	0	13.07	0	13.07
Western Highlands	H	583,448	498,065	498,065	0	13.88	0.59	0	0	14.48	0.16	14.63	0	14.63
Chimbu	H	435,907	363,714	363,714	0	12.05	4.51	0	0	16.56	0	16.56	0	16.56
Eastern Highlands	H	701,660	572,679	565,542	7,137 (1.25%)	17.29	0.68	0	0	17.97	0.41	18.38	1.02	19.40
Western	LC	5,194,206	4,575,048	4,022,038	553,010 (12.09%)	6.45	2.90	0	0.93	10.28	1.64	11.92	10.65	22.57
Gulf	LC	2,522,310	2,367,151	2,029,969	337,182 (14.24%)	5.03	0.02	0	0	5.05	1.10	6.15	13.37	19.52
Central	LC	2,382,124	1,963,004	1,783,019	179,985 (9.17%)	12.96	1.01	0.16	0	14.13	3.46	17.59	7.56	25.15
Milne Bay	LC	1,134,974	926,031	825,401	100,630 (10.87)	14.67	0.19	1.08	0.07	16.01	2.40	18.41	8.87	27.28
Oro	LC	1,793,923	1,559,545	1,469,458	90,087 (5.78%)	9.44	1.06	0.38	0	10.87	2.19	13.07	5.02	18.09
Morobe	LC	2,641,800	2,096,544	1,986,415	110,129 (5.25%)	15.77	1.84	0	0	17.61	3.03	20.64	4.17	24.81
Madang	LC	2,419,307	1,994,812	1,921,034	73,778 (3.70%)	15.13	0.49	0	0	15.61	1.93	17.55	3.05	20.60
East Sepik	LC	2,371,213	2,046,917	2,002,745	44,172 (2.16%)	12.73	0.36	0.12	0	13.21	0.47	13.68	1.86	15.54
West Sepik	LC	3,105,473	2,728,396	2,488,155	240,241 (8.81%)	10.17	0.58	0	0	10.75	1.39	12.14	7.74	19.88
Manus	I	150,700	124,000	102,381	21,619 (17.43)	11.22	0.00	0	0	11.22	6.49	17.72	14.35	32.06
New Ireland	I	820,606	646,802	387,405	259,397 (40.10%)	8.78	0.85	0.16	0.10	9.90	11.28	21.18	31.61	52.79
East New Britain	I	1,358,933	1,138,487	885,377	253,110 (22.23%)	7.45	0	0.58	0	8.03	8.19	16.22	18.63	34.85
West New Britain	I	1,847,904	1,499,119	857,201	641,918 (42.82%)	3.19	0.49	3.16	0	6.84	12.03	18.87	34.74	53.61
Bougainville	I	707,584	466,739	466,739	0	34.04	0.00	0.00	0	34.04	0	34.04	0	34.04
PNG Total		**33,227,590**	**28,251,967**	**25,332,253**	**2,919,714 (10.33%)**	**10.83**	**1.04**	**0.28**	**0.15**	**12.30**	**2.67**	**14.97**	**8.79**	**23.76**

Table A1: Forest change in PNG. Summary statistics 1972-2002. Change percentages are net percentages of primary forest area in 1972 that were deforested (DF), degraded (DG), deforested or degraded (Tot) by 2002 listed according to causes: F=Forestry, NF=Non-forestry (Sub.=Subsistence, Plant.=Plantation, Min.=Mining,), Tot.=Total(F+NF). Zones: H=Highlands, LC=Mainland lowland coastal, I=Islands. *Percentage of forest in 2002 which is degraded. In Bougainville there has been no commercial logging since 1988 due to civil conflict (Regan & Griffin, 2005) and records of the extent of logging prior to the conflict are unreliable. For this reason all forest clearance in Bougainville is recorded as non-forestry related (34.04%) despite the likelihood that a percentage of this was forestry-related.

Province	Zone	Accessible Forest 1972 (ha)	Accessible Forest 2002				1972-2002 Change								
			Total (ha)	Primary (ha)	Degraded (ha (%))*	Primary unlogged but allocated (%)	DF (%)						DG (%)	DF & DG (%)	
							F	NF				Tot.	F	F	Tot.
								Sub.	Fire	Plant.	Tot				
Southern Highlands	H	343,045	312,795	305,476	7,319 (2.34%)	30.36	1.30	7.52	0	0	7.52	8.82	2.13	3.43	10.95
Enga	H	27,344	13,996	13,996	0 (0%)	100	0	48.82	0	0	48.82	48.82	0	0	48.82
Western Highlands	H	74,611	66,643	66,643	0 (0%)	100	1.23	9.45	0	0	9.45	10.68	0	1.23	10.68
Chimbu	H	52,085	50,601	50,601	0 (0%)	0	0	2.85	0	0	2.85	2.85	0	0	2.85
Eastern Highlands	H	10,007	7,137	0	7,137 (100%)	0	28.68	0.00	0	0	0	28.68	71.32	100	100
Western	LC	3,929,073	3,614,867	3,061,857	553,010 (15.30%)	42.04	2.17	5.73	0.10	0	5.83	8.00	14.07	16.24	22.07
Gulf	LC	1,434,277	1,352,858	1,015,676	337,182 (24.92%)	61.72	1.94	3.73	0	0	3.73	5.68	23.51	25.45	29.19
Central	LC	623,255	497,876	317,891	179,985 (36.15)	43.19	13.23	6.27	0.02	0.59	6.89	20.12	28.88	42.11	49.00
Milne Bay	LC	328,349	264,195	163,565	100,630 (38.09%)	65.37	8.31	7.50	0	3.73	11.23	19.54	30.65	38.96	50.19
Oro	LC	758,151	618,106	528,019	90,087 (14.57%)	19.64	5.19	12.39	0	0.89	13.28	18.47	11.88	17.07	30.35
Morobe	LC	303,878	202,588	92,459	110,129 (54.36%)	100.00	26.33	7.00	0	0	7.00	33.33	36.24	62.57	69.57
Madang	LC	750,962	639,350	565,572	73,778 (11.54%)	55.55	6.23	8.61	0.02	0	8.63	14.86	9.82	16.06	24.69
East Sepik	LC	507,226	446,060	401,888	44,172 (9.90%)	33.37	2.20	9.32	0	0.54	9.86	12.06	8.71	10.91	20.77
West Sepik	LC	1,455,371	1,275,661	1,035,420	240,241 (18.83%)	47.97	2.97	9.38	0.00	0	9.38	12.35	16.51	19.48	28.86
Manus	I	102,894	78,552	56,933	21,619 (27.52%)	23.45	9.51	14.15	0	0	14.15	23.66	21.01	30.52	44.67
New Ireland	I	500,605	377,596	118,199	259,397 (68.70%)	61.21	18.49	4.57	1.25	0.27	6.09	24.57	51.82	70.30	76.39
East New Britain	I	645,636	498,727	245,617	253,110 (50.75%)	87.14	17.24	4.30	0	1.21	5.51	22.75	39.20	56.45	61.96
West New Britain	I	1,438,143	1,117,691	475,773	641,918 (57.43%)	90.72	15.46	2.76	0	4.07	6.82	22.28	44.64	60.09	66.92
Bougainville	I	190,076	168,195	168,195	0 (0%)	24.98	0	11.51	0	0	11.51	11.51	0	0	11.51
PNG Total		**13,474,988**	**11,603,494**	**8,683,780**	**2,919,714 (25.16%)**	**48.90**	**6.59**	**6.53**	**0.08**	**0.69**	**7.30**	**13.89**	**21.67**	**28.25**	**35.56**

Table A2: Area and change in commercially accessible forests 1972-2002. Change percentages are net percentages of primary forest area in 1972 that were deforested (DF), degraded (DG), deforested or degraded (Tot) by 2002 listed according to causes: F=Forestry, NF=Non-forestry (Sub.=Subsistence, Plant.=Plantation, Min.=Mining), Tot.=Total(F+NF.) Zones: H=Highlands, LC=Lowland coastal, I=Islands. *Percentage of forest in 2002 which is degraded. In Bougainville there has been no commercial logging since 1988 due to civil conflict (Regan & Griffin, 2005) and records of the extent of logging prior to the conflict are unreliable. For this reason all forest clearance in Bougainville is recorded as non-forestry related (34.04%) despite the likelihood that a proportion of this was forestry-related.

Table A3: The area of vegetation types and forest change (1972-2002) in PNG's WMAs and NPs, ranked by size.

Name	Total area (ha)	Total Rainforest area 2002 (ha)	Area of Rainforest logged (ha) by 2002	Swamp Forest (ha) 2002	Mangrove (ha) 2002	Area converted 1972-2002(ha)	Rainforest change %
Tonda WMA	608,505	0	0	0	6,477	0	0.0
Crater Mt WMA	269,020	255,306	0	0	0	8,860	3.4
Hunstein WMA	219,929	160,850	0	48,195	0	2,964	1.8
Kamiali WMA	28,353	23,064	0	1,539	49	2,393	9.4
Oia Mada Wara WMA	22,984	18,980	0	0	0	2,653	12.3
Lake Kutubu WMA	21,322	13,117	0	1,445	0	1,117	7.8
Lihir WMA	19,973	10,170	0	0	15	5,904	36.7
Bagiai WMA	17,001	11,966	0	0	0	3,259	21.4
Ranba WMA	13,612	5,144	0	0	0	14	0.3
Siwi Utame WMA	12,528	5,781	0	0	0	2,522	30.4
Poliki WMA	11,952	7,456	7,373	469	5	2,437	99.2
Garu WMA	7,798	5,357	3,251	974	0	898	66.3
Mojirau WMA	6,826	6,468	1,234	0	0	197	21.5
Ndrolowa WMA	5,690	1,689	0	1,277	745	573	25.3
Klampun WMA	5,121	4,311	0	0	0	320	6.9
Jimi Valley WMA	4,360	3,940	0	0	0	343	8.0
Iomare WMA	3,943	26	0	0	0	3,291	99.2
Lake Lavu WMA	2,711	2,009	0	163	0	190	8.6
Neiru WMA	2,414	525	0	8	1,531	0	0.0
McAdams NP	2,117	280	0	0	0	0	0.0
Crown Island WMA	1,395	1,324	0	0	0	0	0.0
Varirata NP	1,033	943	0	0	0	37	3.8
Mt. Nuserang WMA	1,024	900	0	0	0	112	11.1
Zo-Iomage WMA	942	600	0	0	0	161	21.2
Tavalo WMA	926	604	41	0	0	232	32.7
Mt Kaindi WMA	866	394	0	0	0	27	6.4
Sawataetae WMA	790	129	0	262	72	112	46.5
Mt Wilhelm NP	703	215	0	0	0	43	16.7
Balek WMA	577	406	0	0	0	137	25.2
Mt. Gahvisuka WMA	199	154	0	0	0	42	21.4
Hombareta WMA	149	52	52	0	0	63	100.0
Mt Susu WMA	119	0	0	0	0	0	0.0
Namanatabu WMA	55	5	0	0	0	17	77.3
Nanuk WMA	36	0	0	0	0	8	100.0
TOTAL AREA	**1,294,969**	**542,166**	**11,951**	**54,332**	**8,892**	**38,927**	**8.8**
Kikori ICAD	**2,095,062**	**1,663,965**	**76,979**	**62,716**	**128,353**	**104,325**	**10.3**

Annex 2 – Methods

SUMMARY – We mapped recent (2002) forest extent and degradation using high-resolution imagery. We then compared our 2002 forest map with a baseline high-resolution 1972 forest map and measured the 30-year net area of deforestation and degradation across PNG's three distinct regions: the islands, the highlands and mainland lowlands (see Figure 1 on page 6). For each discrete area of deforestation or degradation, we identified the main driver of forest change – either forestry, subsistence agriculture, plantation development, forest fires or mining activities. We used these data to estimate recent net deforestation and degradation rates.

CREATION OF 1972 LAND-COVER MAP – The '1972' land-cover map was digitized from colour separations of Australian Army (T601) 1:100,000 scale vegetation maps. These maps were created by visual classification and manual delineation of polygon class boundaries of vegetation types discernible in very high-resolution (1-2 m) stereo aerial photography taken between 1972 and 1975, but predominantly in 1972 (Coulthard-Clark, 2000). The classification process, as well as extensive geo-referencing and field-verification, was undertaken by the Australian Defence Forces as part of the production of 1:100,000 scale mapsheet series of Papua New Guinea (Coulthard-Clark, 2000). The vegetation classes used in this exercise were intact forest, mangroves, scrub, grassland and water. For the change analysis, land-cover classes were combined into two categories: forest (rainforest) and non-forest (non-rainforest). All forests in the 1972 map were assumed to be primary forests as levels of commercial logging were comparatively low prior to this time (Hammermaster & Saunders, 1995; McAlpine & Freyne, 2001).

CREATION OF 2002 LAND-COVER MAP – To create a new land-cover map of PNG, we acquired multi-band imagery from the Landsat Enhanced Thematic Mapper Plus (ETM+) and Systeme Pour l'Observation de la Terre (SPOT) 4 and SPOT 5 sensors. Due to almost perpetual cloud-cover, we were unable to obtain suitable cloud-free 30 m resolution (15 m panchromatic) Landsat ETM+ imagery for the whole of PNG. In areas not covered by Landsat, we acquired SPOT 4 or SPOT 5 (20 and 10 m resolution respectively) instead. About 18 percent of PNG was classified from imagery recorded in 2000-2001, 62 percent in 2002 and 20 percent in 2003-2007: accordingly we term the land-cover map '2002'.

In total we used 80 SPOT 4 and 5 images and 25 Landsat ETM+ images to obtain cloud-free coverage for the whole of PNG. Each satellite image was orthorectified using 10-15 ground control points derived from the 1972 land-cover maps (Coulthard-Clark, 2000) and a 90 m Digital Elevation Model (DEM). The average positional Root Mean Square Error for the orthorectified imagery was 25-30 m for Landsat ETM+ and 15-20 m for the SPOT 4 & 5 imagery.

We applied a Tasseled Cap and Brovey transformation (Kauth & Thomas, 1976) to our 2002 Landsat ETM+ imagery, and red/green/blue/infrared colour enhancement to our SPOT 4 & 5 imagery. We used the object recognition software 'eCognition' (Definiens, 2005) to automatically segment the satellite imagery into spatially continuous and spectrally homogeneous regions consistent with land-cover features, and to vectorize them into individual polygons. The process of image segmentation and vectorization is summarized in Figure 38:

Figure 38: The process of image classification showing the 7 principle steps.

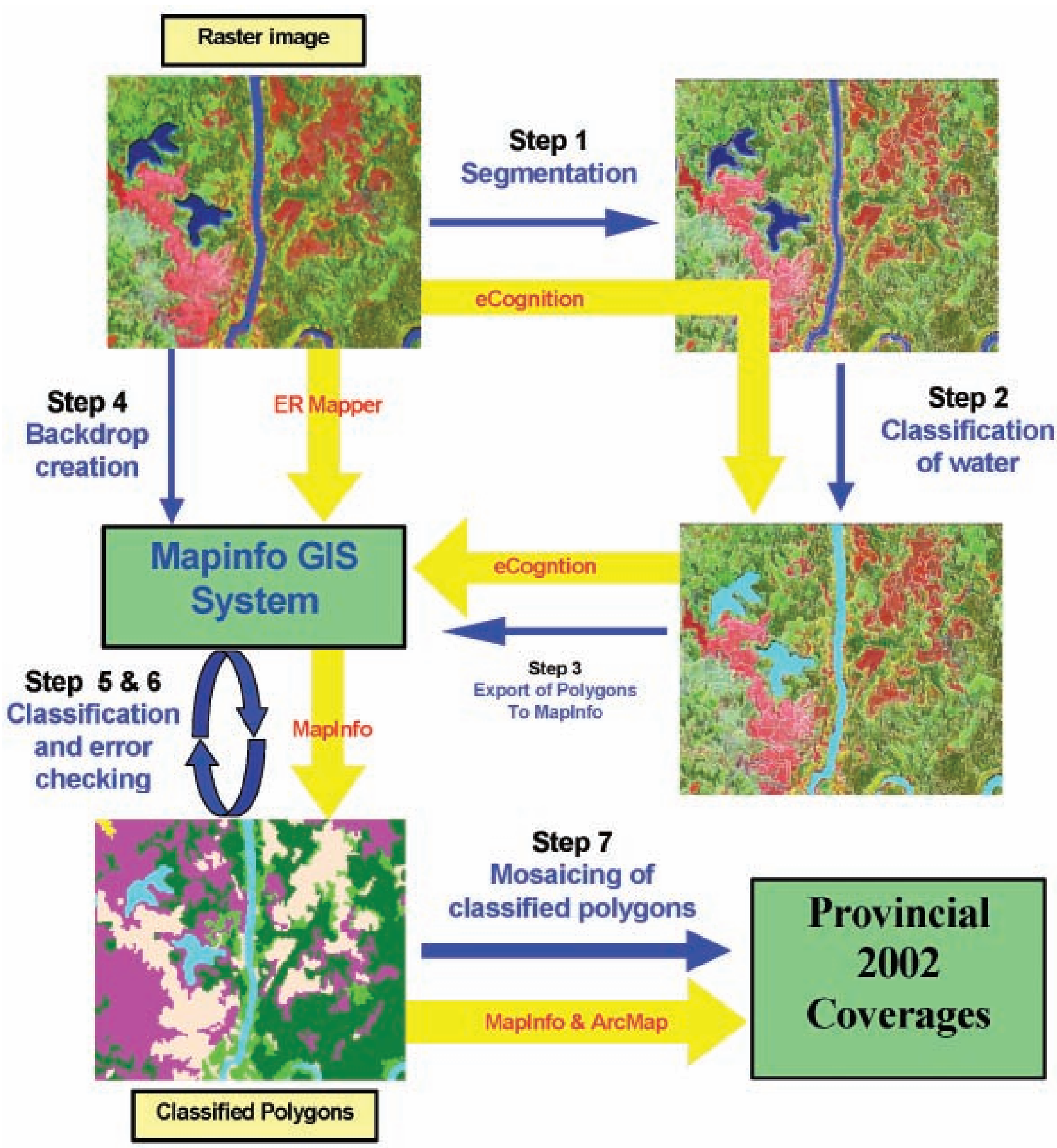


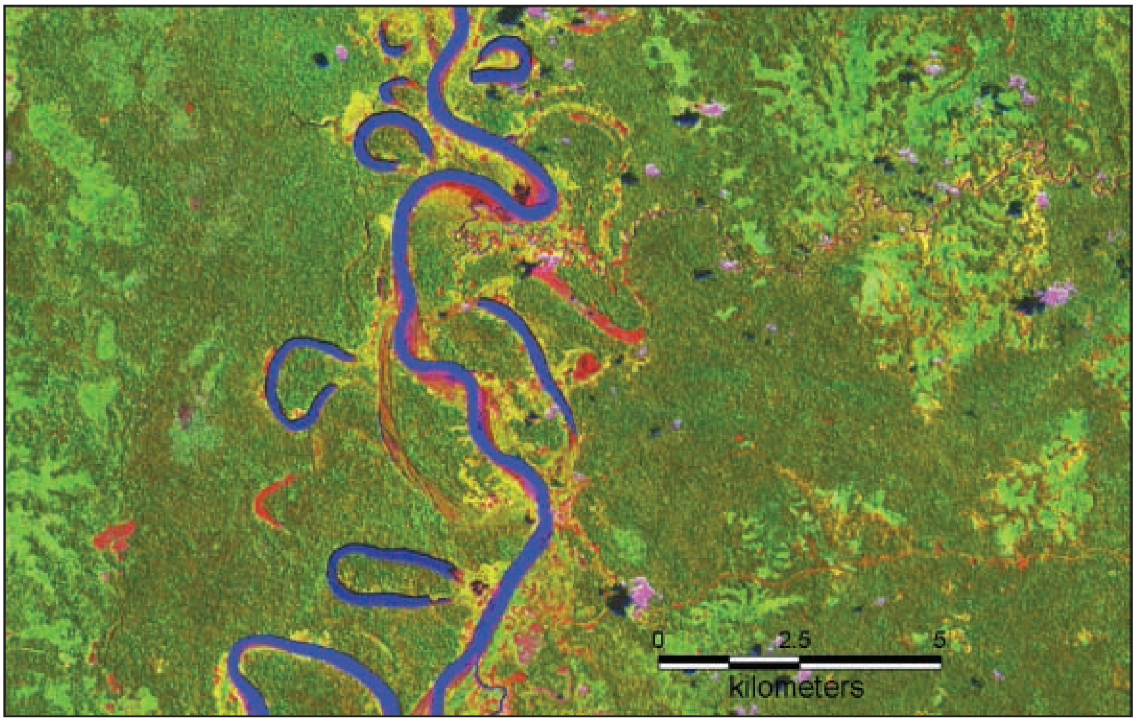
IMAGE CLASSIFICATION – We used a technique that combined automated digital pattern recognition (Definiens, 2005) and expert visual interpretation (Lu et al, 2004), to classify the satellite imagery of PNG into basic land-cover classes at a 10-30 m pixel resolution. The basic land-cover classes used were: tropical rainforest (referred to here as 'forest'), swamp forest, dry evergreen forest, mangroves, scrub, herbaceous swamp, non-vegetation, water and grassland. Within the change analysis, land-cover classes were grouped into two categories: forest (rainforest) and non-forest (non-rainforest). Decision rules used to define land-cover classes are outlined in Table A4 based on our Tasseled Cap and red/green/blue/infrared image enhancements.

Table A4: Characteristics used to define land-cover classes.

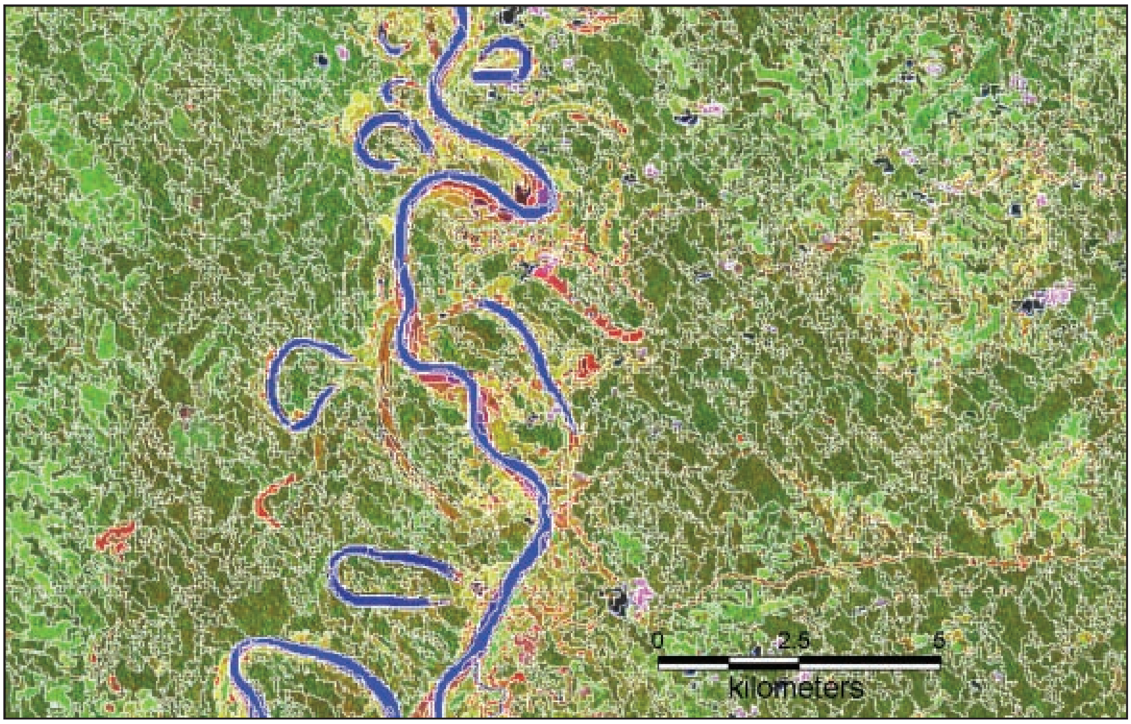
CLASS	CLASS CHARACTERISTICS
Intact Rainforest (F)	Generally dark green, and homogenous. Polygons large relative to other classes and possess distinct mottled texture due to differences in individual canopy reflectances.
Secondary Rainforest – Logged (Fl)	This class is separated from Intact Forest post-classification.
Scrub (D)	Generally light-green or yellow-brown in colour on most backdrops. Relatively small and irregularly shaped polygons of variable texture. Secondary vegetation or scrub is generally found surrounding village areas on the sides of roads or in riverine successions. Where gardens are present they are often interspersed with the red speckles of newly cleared sites (N). The presence of fire hotspots assists in the determination of D, especially in areas of burned forest. Areas of forest that had been burned were occasionally visible in some images.
Non-Forest (N)	Grassland, roads, and other non-vegetated areas generally reflect a high proportion of incident radiation in all bands. For this reason these features are generally bright, and usually pink or red in colouration. Freshly cleared areas in gardens appear as small red speckles. Areas of grassland appear as very homogenous, large red areas, contrasting with surrounding green vegetation.
Swamp Forest (S)	Swamp Forest can be discerned by its smooth texture, light green colouration and in the southern provinces, its dendritic pattern of occurrence. It occurs in areas that are relatively flat, often in proximity to water courses and the coast.
Herbaceous Swamp (H)	Non-Woody Swamp Vegetation appears in relatively small areas, usually surrounded by water or swamp forest. Usually it is coloured lime green and possesses a very smooth texture.
Dry Evergreen Forest (E)	Closest to Forest in its appearance, however there is rough canopy texture and small brown gaps. This is because the canopy is often broken and less dense than that of Forest. Intergrades into Savannah/Grassland and occurs only in Western Province.
Water (W)	Blue areas. In the case of rivers, the features are sinuous in shape and occur in valley bottoms. Lakes are generally delineated as regularly shaped polygons.
Mangrove (M)	Mangroves appear as intensely dark green features, often with a blue tinge, and occur in close proximity to the sea.

An illustrated example of the classification process is outlined on this and the following pages:

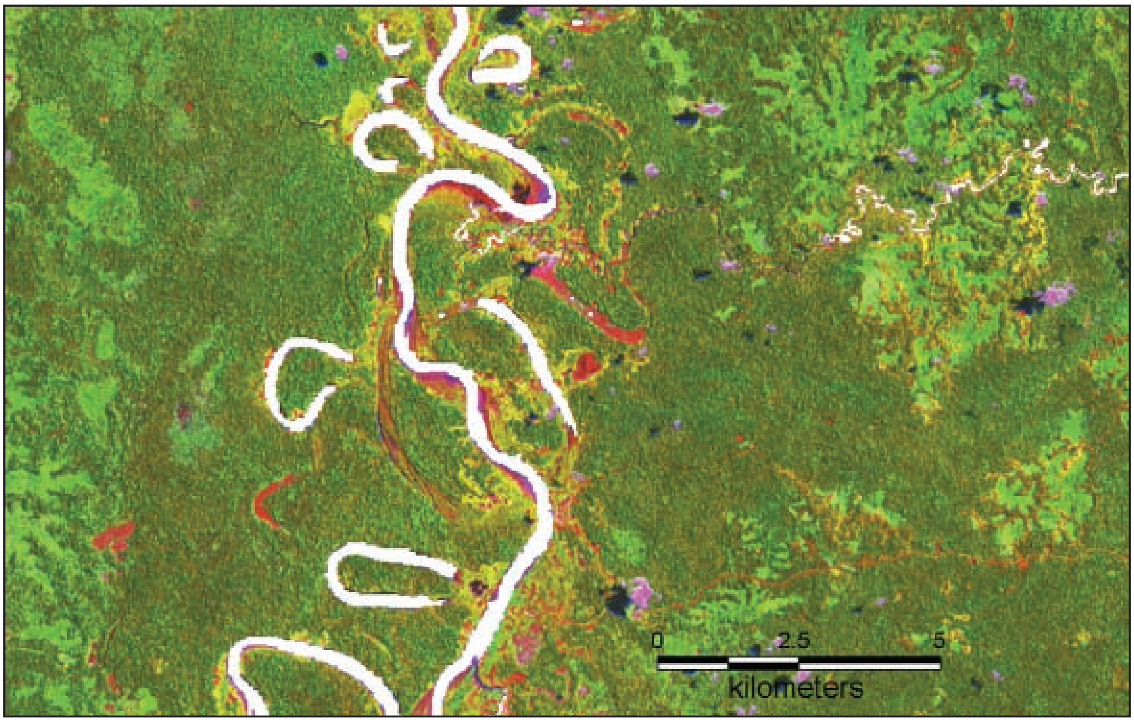
i) The Ramu River runs though the centre of the image and is surrounded by oxbow lakes. The river is flanked by the gardens of numerous villages, seen as yellow-brown areas with red speckles. Some dry oxbows that are covered in grassland are displayed as red areas. A road can be seen in the lower right of the image. There are some areas of scrub flanking the road. The majority of the image is filled with the dark green of Intact Rainforest. However in the east and west, swamp forest is displayed as light green vegetation. It often possesses the distinctive leaf-like patterns of blocked valley swamps. A scattering of pink-puff clouds and their cloud shadows can also be seen in parts of the image.



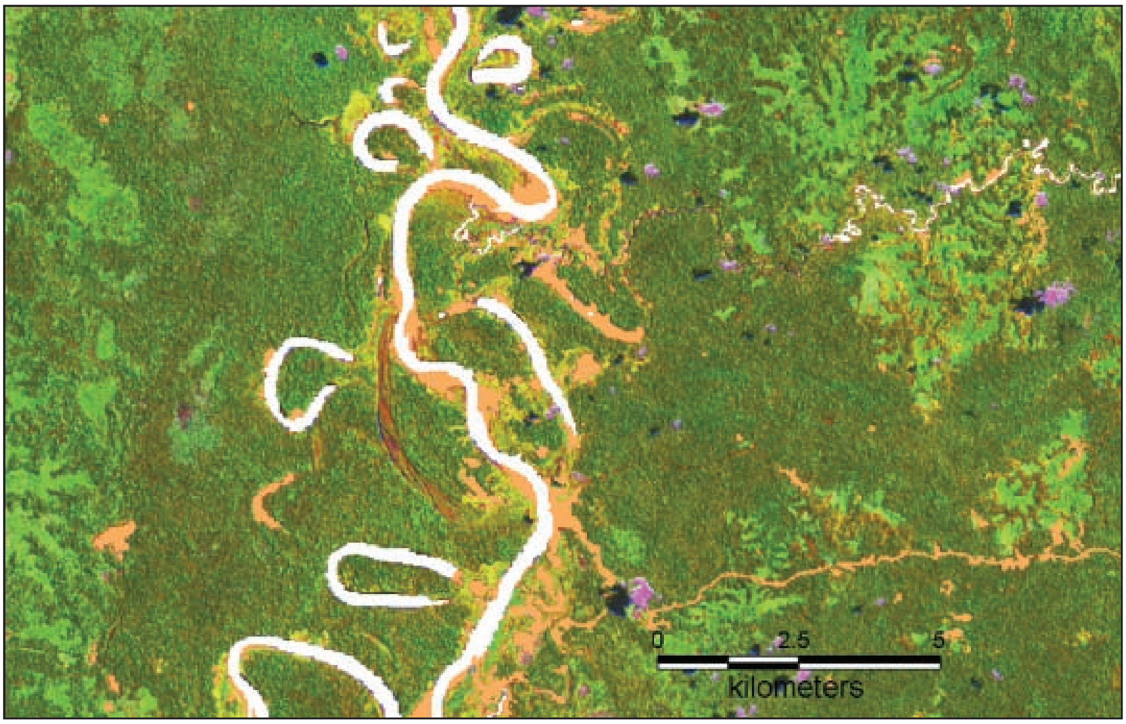
ii) This image is of the same area with the eCognition-derived polygons overlain in white polygon perimeters.



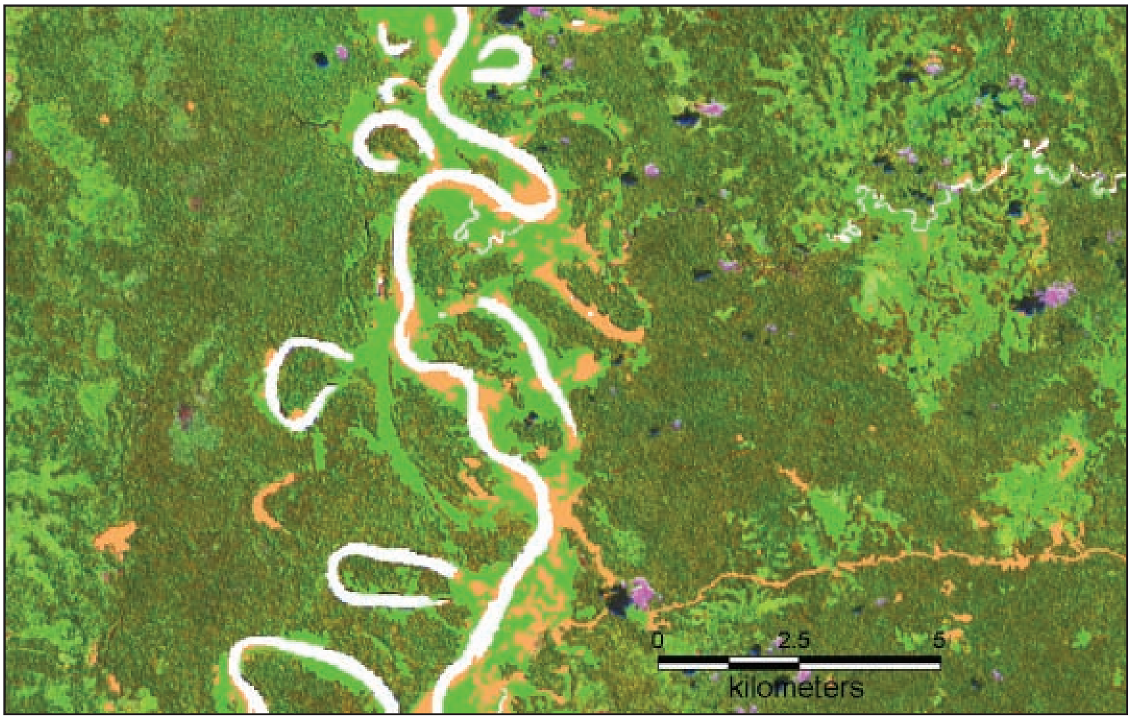
iii) In this scene the Water (W) class, derived within eCognition is displayed in white. Other polygons are transparent. This classification is visually checked and if need be, modified. The parameters used within eCognition for polygon generation were in some images, poor at differentiating rivers and shaded slopes in mountainous regions. To resolve this issue, problem polygons were manually split so that a true representation of the river area could be obtained.



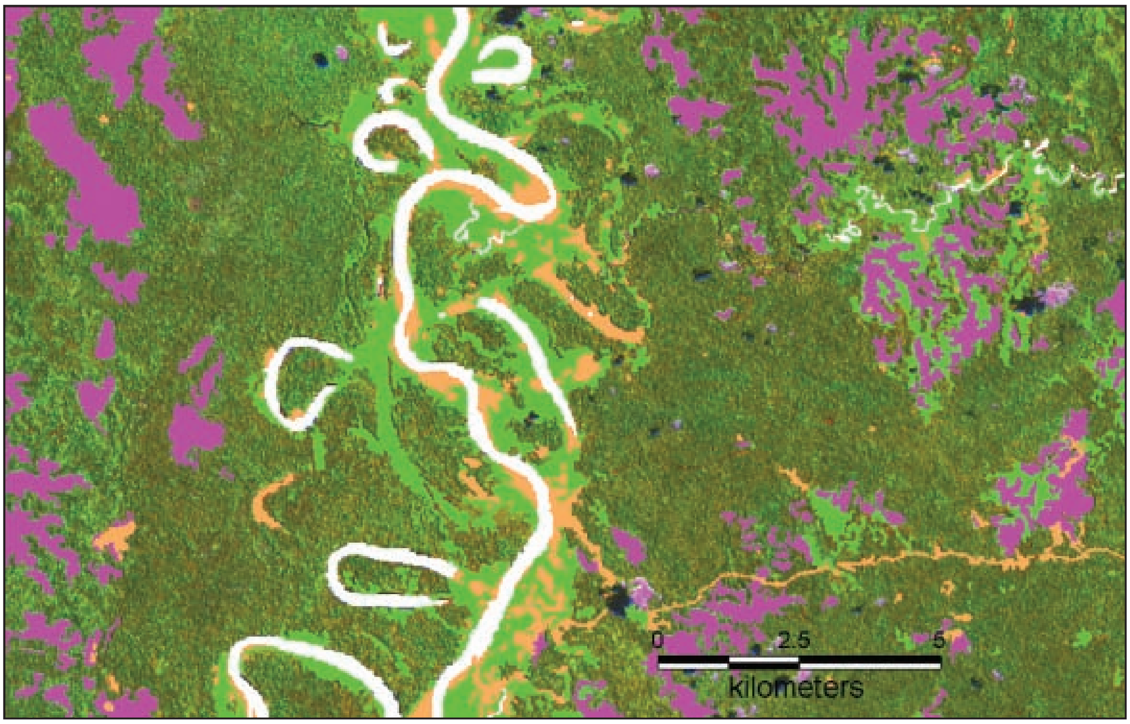
iv) The next classification step is the classification of Non-Forest regions (N). Within MapInfo the N classification is made by manually selecting the polygons and giving their fields this value. These areas are displayed here in orange. Note the road in the bottom right of the scene and areas of highest village intensity along the river. Areas of grassland in the old oxbows are also given this classification.



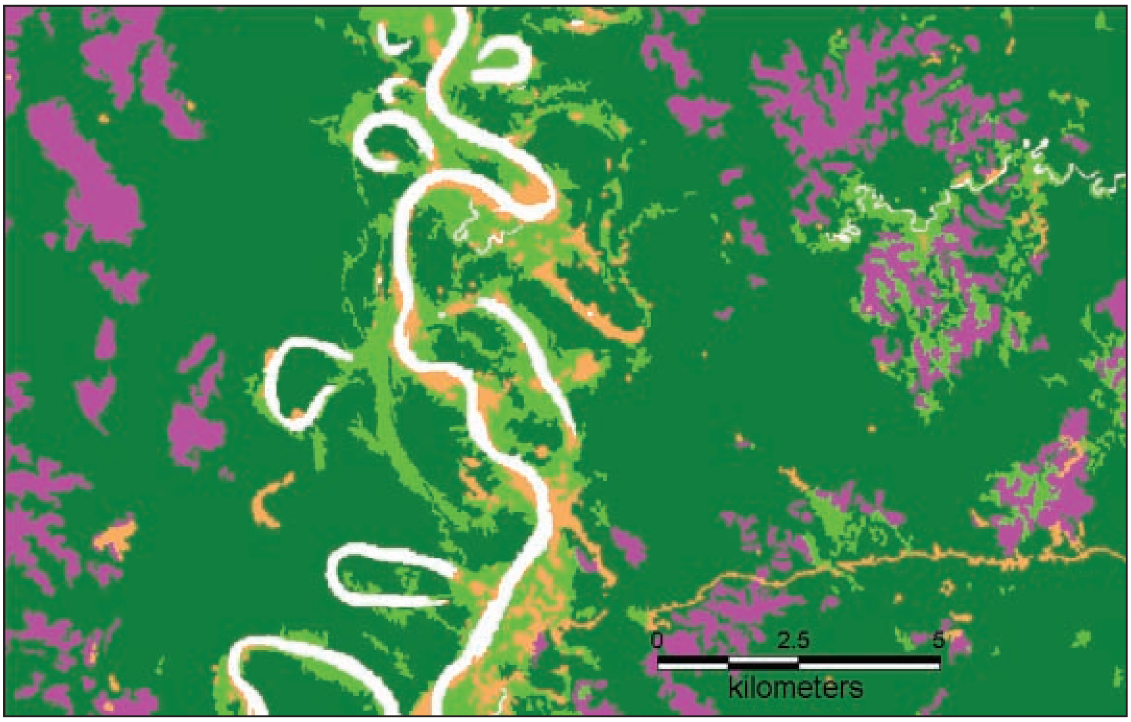
v) The D classification is made capturing secondary vegetation areas around the villages as well as riverine successions. D is presented here in **light-green**.



vi) Areas of Swamp Forest (S) are then classified and are displayed here in **purple**.



vii) Finally, all the remaining polygons in the scene are classified as intact rainforest (F) displayed here in **dark-green**. Note that the clouds and their corresponding shadows have been given the classification of the polygons immediately surrounding them. Where this is confused by a number of proximal classifications, such as in the area where the road joins the river, immediately to the north of the scale bar, a default of the Rainforest (F) classification is applied.



METHOD OF CHANGE DETECTION – Areas of forest change were detected by the superimposition of the 2002 land-cover map with the 1972 map. Areas that were forest in 1972 but were not in 2002 were designated as 'forest loss'. Areas that were not forest in 1972 but were forest in 2002 were designated as 'forest gain'. Change statistics were produced by subtracting the total area of forest gain from the area of loss, hence we measured 'net' rather than gross loss. The change detection process is summarized in the following examples, that relate to the figure on the opposite page (Figure 39).

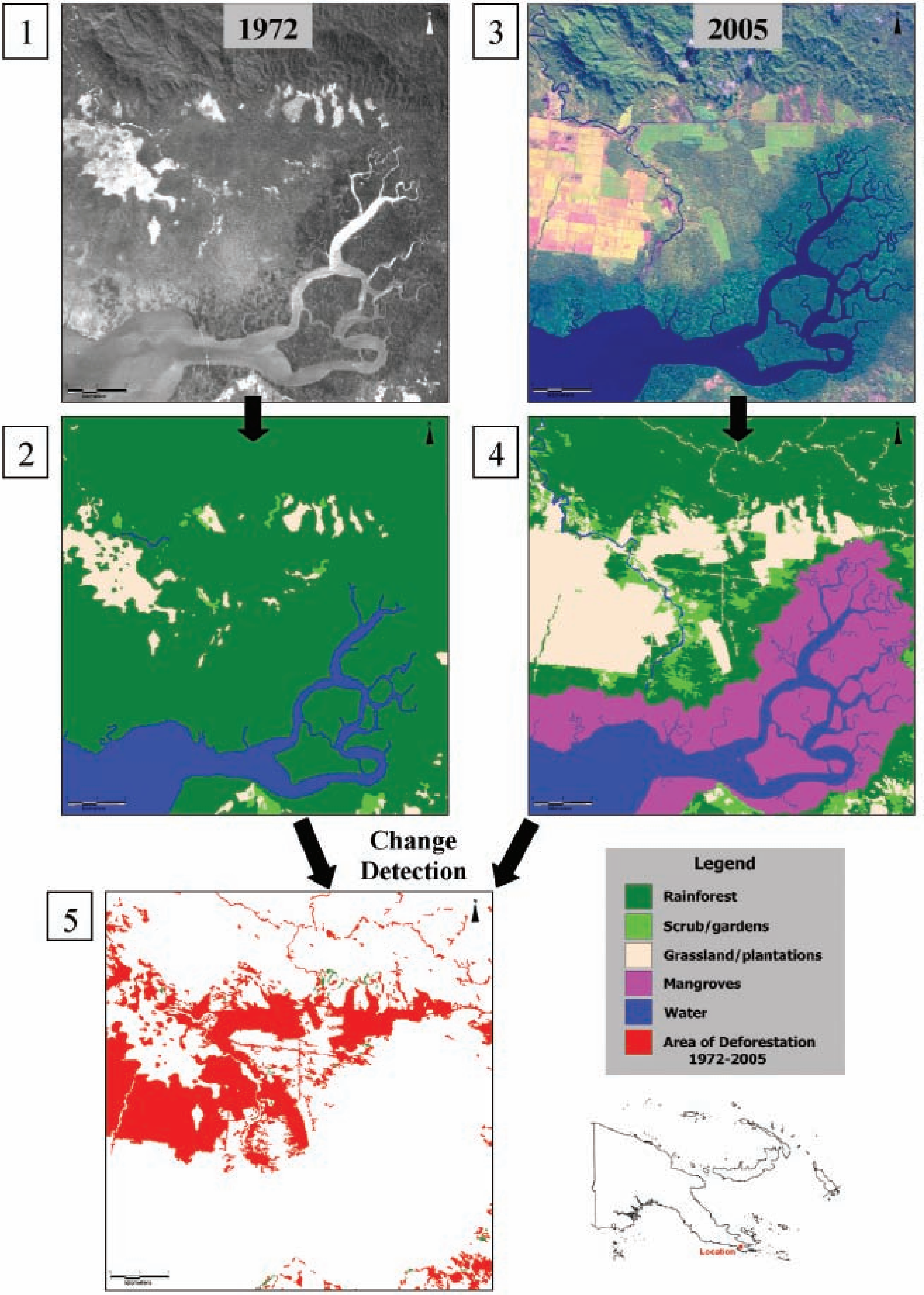
1. An example of the aerial photography recorded by the Australian Army in 1972. Areas of grassland, scrub and garden are clearly visible.

2. The Australian Army classified these images into four basic land-cover types: forest (including mangroves and swamp forest), scrub/gardens, grassland and water. This study vectorized these land-cover maps for the entirety of PNG to generate a land-cover classification from 1972.

3. An example of imagery (SPOT5) acquired over the same site in 2005. Large areas of rainforest have been cleared to make way for oil palm plantations. Expansion of garden sites is apparent in the southern portions of the image and logging roads visible in the northern portions.

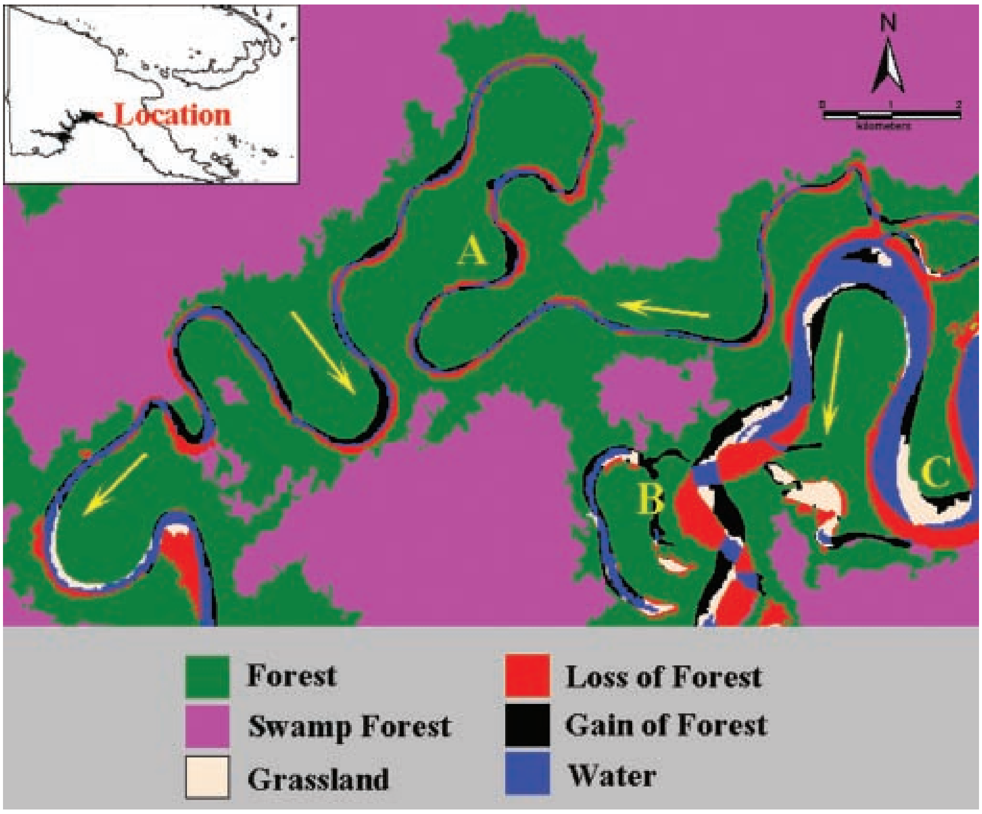
4. The study classified the image into five classes equivalent and comparable with the 1972 classification: Rainforest, mangroves, scrub/gardens, grassland and water. This classification process was used to create a thematic vector coverage for the whole country.

5. The rainforest (and mangrove) classes from both the 1972 and 2005 coverages were superimposed to allow change detection. Subtraction of 2005 rainforest (and mangrove) areas from 1972 rainforest areas provides an estimate of the area of deforestation between 1972 and 2005. Subtraction of 1972 rainforest areas from 2005 rainforest (and mangrove) areas provides an estimate of the area of scrub/gardens that have regained an intact canopy between 1972 and 2005. The areas of deforestation (in red) and reforestation (in dark green) are apparent in this image. Note that the 1972 mapping of rivers was made on a different colour separation to the one used in this process. For this reason any area of 'loss' generated by this change detection process that was located within a region classified as 'water' in the 2002 classification, was deleted.


1
1972
3
2005
2
4
Change
Detection
5
Legend
Rainforest
Scrub/gardens
Grassland/plantations
Mangroves
Water
Area of Deforestation
1972-2005
Location

An informative qualitative example of the change detection results can be seen in Figure 40 in which an actively meandering river has been recorded in the change detection process. The process of meandering has caused forest loss on the eroding outside of the meanders, and forest gain on the inside as vegetation colonises accreting areas. Such examples gave confidence that the technique was recording real change, both loss and gain, in forest cover at a fine resolution.

Figure 40: An example of river meandering recorded in the change detection process. Direction of river erosion of the outer banks on bends banks is shown by yellow arrows, with accretion on the inner part of bends. Note the corresponding loss of forest cover on the outside of meander loops and the gain on forest cover on the inside of the loops. This is especially visible at locations A, B and C. Areas showing 'Loss of forest', are in most locations, when combined with current extent of water, the actual location of the river in 2002. At location C, the process of succession can be seen where a new area of grassland/sediment and some 'Gain in forest' occurs on the inside of the meander loop.



ASSESSMENT OF LOGGED FOREST – We mapped recent logging-related deforestation and degradation using the visual interpretation of logging roads, snig tracks and canopy gaps to delineate a timber extraction radius for all commercial logging activity. Forest within our timber extraction radius was designated as 'degraded' and clearances were designated as 'deforested' due to logging. Areas within logging concessions outside of this radius were assumed not to have been logged.

While the first and second order roads from logging operations are visible in Landsat ETM+ imagery for a decade or longer post-logging, the associated canopy gaps and snig tracks are usually covered over by regrowth within 1 to 5 years (Steininger, 1996; Nepstad et al, 1999) making them difficult to discern from unlogged forest. Older logging is therefore difficult to detect from Landsat imagery (Asner et al, 2005).

For these reasons we used logging roads identified during image classification and where visible, snig tracks, to delineate areas of older logging (>5 years) activity. The use of mapped logging roads as surrogates for assessing the extent of logging has been widely used to overcome problems with automatic classification caused by the relatively minor difference between the spectral properties of logged and unlogged forests (McGurk & Fong, 1995; Stone & Lefebvre, 1998; Souza & Barreto, 2000; Laporte et al, 2007).

This approach was further substantiated by an examination of 14 recently logged sites in which canopy gaps and snig tracks associated with recent logging activity were visible. We found that the maximum distance travelled by skidders away from road landings was approximately 500 m, with the majority occurring within 100-300 m. For older logged areas where logging extent was unclear from the imagery, we manually delineated a timber extraction radius to a maximum of 500 m around logging roads. However in most locations the manually delineated extent of logging was less than this distance.

In those areas where logging ceased more than a decade ago and where logging roads were themselves not visible, data from previous helicopter surveys of logging activity (Hammermaster & Saunders, 1995) were used to demarcate logged areas. Forest within these areas was delineated as 'degraded' and cleared areas were delineated as 'deforested' due to logging. This use of the helicopter survey data only occurred in relatively few locations as in most places older roads are still visible because of recent use unrelated to logging, or because those areas that were logged in the 1980s have since been cleared.

Our assessment would have failed to detect additional logging through the local use of portable sawmills; however, this is a relatively minor component of the total National logging effort (ODI, 2006). Our measurement of the extent of deforestation and degradation due to logging is therefore a slight underestimate.

ASSESSMENT OF FOREST LOSS DUE TO FIRE – Forest clearance as a consequence of subsistence agriculture frequently involves burning that commonly spreads a distance into adjacent vegetation. This clearance was designated as being subsistence-related. There were however, some extensive fires in primary forest not associated with subsistence agriculture. In many locations, large areas of burned forest could be recognised by their distinct spectral response (Nepstad et al, 1999) coupled with reports from field workers. The identification of 'burned' forests was assisted in numerous locations by the presence of fire 'thermal hotspots' derived from the Moderate Resolution Imaging Spectroradiometer product (MODIS 14) that showed the location of recent fires (Giglio et al, 2003). In other locations, areas of fire-related loss were recognised due to their large distance (>10 km) from zones of subsistence or commercial use, their distinct pattern, or in the case of montane forest loss, their location on the tops of mountain ranges, usually adjacent to existing grassland. We defined the upper montane zone in our land-cover maps as the region above 2,800 m elevation, consistent with the definition of the 'Tropical Montane' life zone in PNG (McAlpine et al, 1983). The region above 2,800 m elevation was delineated using a 90 m DEM.

ASSESSMENT OF FOREST LOSS DUE TO PLANTATIONS AND MINING DEVELOPMENT – Areas of deforestation that occurred within currently established plantations were deemed to have been cleared to create the plantation. Areas of forest replaced by the open pits of mining operations and associated infrastructure, as well as the tailings-related dieback downstream from the Ok Tedi mine were deemed to have been cleared due to mining. This assessment of mining-related deforestation does not include increased agriculture that may be associated with the mining projects (Dambacher et al, 2007).

ASSESSMENT OF FOREST LOSS DUE TO SUBSISTENCE AGRICULTURE – Subsistence agriculture was usually discernible in the imagery. Areas of forest loss adjacent to either subsistence gardens or rural villages were deemed to be subsistence-related. Areas of deforestation that could not be attributed to other drivers of forest change were also ascribed to have occurred through subsistence activities.

ASSESSMENT OF COMMERCIALLY ACCESSIBLE FORESTS – Areas of polygonal karst, slopes too steep for mechanized logging and Wildlife Management Areas were delineated as physically 'inaccessible'. Forests growing on polygonal karst in our 1972 and 2002 land-cover map were identified using a landform map (Loffler, 1977) and our 2002 satellite imagery. Slopes too steep to log were identified using a slope surface derived from a 90 m resolution digital elevation model (DEM). We created the DEM from Shuttle Radar Topography Mission (SRTM) data (Farr et al, 2007), corrected for the effects of radar shadow in steep valleys using a DEM created from 1:100,000 and 1:250,000 contour maps of PNG (Coulthard-Clark, 2000). The resulting DEM was calibrated against a high-resolution (15m) DEM. We found that approximately 95 percent of the logged areas in our 2002 land-cover map occurred on slopes less than 25^{o}. We therefore used 25^{o} as the limit for commercial logging access in PNG. This concurs with the assessments in the Wet Tropics of North Queensland that found forests on slopes greater than 28^{o} had a zero probability of being logged (Vanclay, 1994).

Forested areas too small to support a commercial logging operation (50,000 ha) were delineated as economically 'inaccessible'. The World Bank determined that commercially viable forestry operations in PNG required an annual timber extraction volume of 70,000 m^3 over 35 years (World Bank & GoPNG, 2001). We conservatively applied a smaller area (50,000 ha) as the lower limit for commercial viability since many concessions are only exploited for 10-15 years and many logging companies operate under marginal economic conditions (ODI, 2006).

DETERMINATION OF CHANGE RATES – Change rates are commonly calculated by dividing the measured area of forest loss as a percentage of forest area evenly over each year in the time period (Puyravaud, 2003). This method assumes constant decline over the time period. As our analysis was long term the assumption of constant decline was implausible. This is because timber exports, oil palm exports and population, associated with forestry, plantation development and subsistence clearance increased substantially in the latter half of the 30-year time period (see Figures 7 and 13).

We estimated recent change rates by modelling annual clearance over 30 years using timber exports, population data and El Niño magnitude and intensity, rather than using a method that assumed a constant decline in forest cover over the analysis time period. We used this technique because it is unlikely that forest change has proceeded at a constant pace between 1972 and 2002. PNG's population grew exponentially between 1972 and 2002 (FAOSTAT, 2005) (Figure 13) and we found subsistence-related clearance to be closely related to provincial population density ($R^2 = 0.98$, $F = 20.0$, $p < 0.0001$: Figure 15). Thus subsistence-related deforestation is likely to have increased more rapidly in recent years. Timber and oil palm exported from PNG increased relatively slowly until the mid 1980's, but rose sharply in the early 1990's (see Figure 7 for timber exports). Thus the majority of logging and plantation-related clearance likely occurred in the latter half of our 30 years time period. Similarly, deforestation of primary rainforest due to fire is often related to intense El Niño drought events (Holdsworth & Uhl, 1997), which did not occur annually between 1972 and 2002.

We apportioned the total area of forestry-related deforestation and degradation to each year according to the volume of timber exported from logging concessions in that year (Gresham, 1982; Hunt, 2002; SGS, 2005-2007). We apportioned the total area of plantation-related deforestation on an annual basis according to lagged (4 years) oil palm exports from each year (PNG Oil Palm Research Association, unpublished data). We apportioned the total area cleared due to subsistence agriculture using the population of each year between 1972 and 2002 (FAOSTAT, 2005). We apportioned the fire-related clearance to individual years based on the occurrence, intensity and duration of El Niño events between 1972 and 2002 (Yue, 2001). For El Niño events spanning multiple years, the duration of the event in each year was used to further apportion fire-related clearance to individual years. Mining-related clearance was apportioned evenly to each of the 30 years due to lack of data on the periodicity of mine-related deforestation. As the area cleared for mining is relatively small, this is unlikely to impact on our estimates of overall rates of forest change. We then estimated the recent forest change rate as the percentage of 2001 forest area cleared or degraded 2001-2002.

VALIDATION OF THE 2002 LAND-COVER MAP – Validation of our 2002 classification was conducted using two low elevation aerial photographic surveys (resolution 0.1-1 m) of 431 locations in West New Britain and Madang provinces during 2004 and 2008. All land-cover types in the 2002 classification were present in these surveys. The flight paths of the surveys are shown in Figure 41. In total, 431 vertical photos were captured, mostly at approximately 1000 m above the ground, and their location recorded using a GPS. The area covered by each image was approximately 1 km^2. Each image was manually assigned to one of the classes used in the classification process. Where a photograph contained more than one class, the image was sub-divided into 9 equal rectangular areas and the centre rectangle classified. The classification was then compared to the classification of the satellite imagery over the same location.

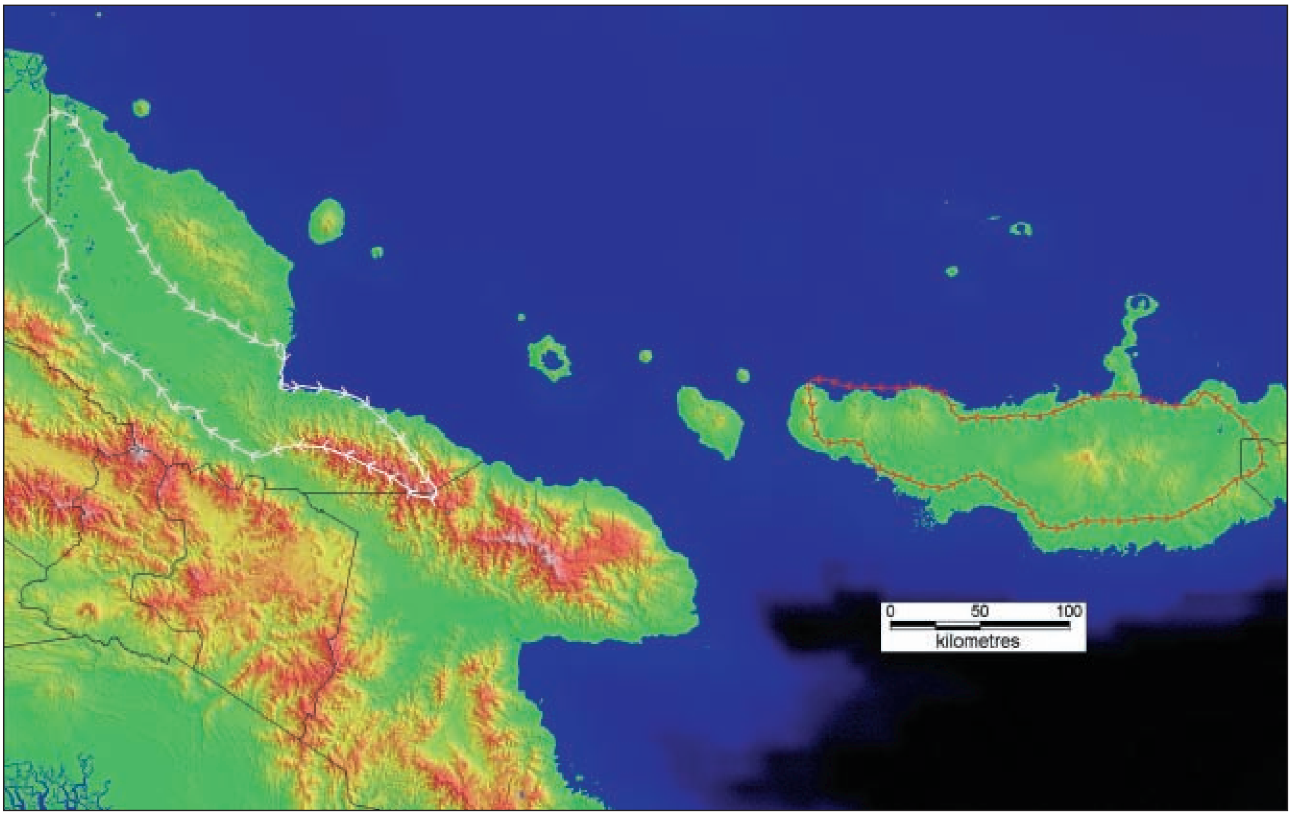
We found that 420 of the 431 images surveyed, or 97.7%, were correctly classified. Mismatches were found in 2.2% of the imagery classifications in which scrub had been confused with grassland. None of the forest classification samples were found to be erroneous. We conclude that our classification was robust because it was conducted at a scale where it is difficult for a trained human observer to be mistaken when discriminating between basic vegetation classes. Discrepancies arose only in the subjective location of fixed boundaries between transitional vegetation types.

ACCURACY ASSESSMENT OF 1972 VEGETATION CLASSIFICATION AND CHANGE DETECTION

Assessing the accuracy of change detection procedures is difficult (Lu et al, 2004). This is especially so in PNG where additional recent imagery is difficult to acquire, and where suitably accurate datasets from the 1970s independent of our own 1972 map do not exist. Consequently we assessed change detection accuracy using the area of forest gained between 1972 and 2002. The 1972 land-cover map provided a reliable indication of actual vegetation cover across the entire nation due to its very-high resolution and the extensive georeferencing and field verification undertaken during its production by the Australian Defence Force (Coulthard-Clark, 2000). The change assessment, comparing our 1972 and 2002 land-cover maps, was bi-directional, estimating both loss and gain in forest cover. Forest gain occurred either through the conversion of non-forest to forest cover, or through error. Grassland could not become intact forest within a period of less than 30 years, so forest gain between 1972 and 2002 consisted of the regeneration of scrub to forest or was an artefact of error in the comparison. Forest gain therefore provided an upper limit on error in the change assessment.

Across the entire country 5.2 percent of total forest change was due to gain, so we estimated that the accuracy of change assessment was greater than 94.8 percent. An assessment of the source of all gain polygons indicated that 23 percent represented actual re-establishment of forest cover from shrub cover and the accuracy of change assessment was therefore 96.0 percent. The positional accuracy of our imagery meant that forest boundary changes between the 1972 and 2002 land-cover maps of 60-100 m could be detected. Within these spatial limitations, we conclude the change detection accuracy was 96.0 percent.

Figure 41: The flight routes used in the aerial surveys of West New Britain (Red) and Madang (White).



ESTIMATING LOGGING IMPACT: The volume of timber exported from PNG is only a small fraction of the tree volume that is damaged or killed by logging (Cameron & Vigus, 1993; Abe et al, 1999; Nepstad et al, 1999; Verissimo et al, 1992). In reality, logging kills the majority of merchantable trees, most of which are harvested, and also kills a substantial proportion of non-merchantable trees (Abe et al. 1999, Nepstad et al. 1999, Cameron & Vigus 1993, Verissimo et al. 1992). In addition to the deaths and damage to non-harvested trees, the FAO (1992) estimated that in PNG 10 - 35% of harvested logs are not exported due to low demand or defects and are left in dumps in the forest or at the point of export, burned or sold to be locally processed as sawn timber. Furthermore, log volume does not include the wood in other parts of the tree (branches, roots) which is killed during logging. Estimating the total wood volume from tree deaths associated with logging in PNG requires a measure of the exported log volume, the log volume of trees that were harvested but not exported (trees removed for roading, bridges, skidding, log landings and wastage through a failure to export the log), and the volume of the rest of the harvested trees (branches, roots) (Abe et al, 1999; Verissimo et al, 1992; Cameron & Vigus, 1993; Loffler, 1972; FAO, 1992).

Harvested volume for each of the 13 concessions that commenced operation since 1992, was estimated from the export volume using the FAO (1992) findings that 10 – 35% of the harvested volume is never exported. The volume of the whole tree represented by the log volume was estimated using a multiplier derived by comparing whole tree volume with log volume for several PNG forest inventories (Cameron & Vigus 1993; Loffler, 1972). Finally, the volume of trees killed during logging but not harvested was estimated. For the area logged but not deforested in each logging concession, the tree volume killed but not harvested was estimated using a logging damage to harvest volume function (Verissimo et al, 1992; Abe et al, 1999). For the area of each concession which was deforested, the pre-logging forest volume was estimated and multiplied by the area deforested. Pre-logging forest volume was derived from a measure of forest biomass from across PNG (described below), divided by the weighted density of the logged stand (Hammermaster & Saunders, 1996; Eddowes, 1977; Soerianegara & Lemmens, 1993; Sosef et al, 1998). The average pre-logging total tree volume in the 13 concessions was 726 m^3/ha. Full methods of our assessment of logging impact are documented in a forthcoming publication.

ESTIMATING PNG FOREST BIOMASS: UPNG estimated the live component of forest biomass in PNG forests. This was done by compiling biomass measurements from across PNG, or estimating biomass from complete tree censuses from forest plots across PNG and extrapolating these measurements to unsurveyed forest using the 2002 forest map and bioclimatic information (Brown, 1997; Chave et al, 2005; Saatchi et al, 2007). Both above and below ground live biomass were included in the measurements. .

Logged forest biomass was estimated by subtracting the average total tree biomass killed through logging from the predicted unlogged biomass. The average total tree biomass killed through logging was estimated from the volume removed through logging outlined above and the average weighted stand density of the logged forest (Hammermaster & Saunders, 1996; Eddowes, 1977; Soerianegara & Lemmens, 1993; Sosef et al, 1998). Biomass estimated in PNG extant forests is shown in Figure 6. Full methods are documented in a forthcoming publication.

Annex 3 – A discussion of FAO forest change rates

The commonly cited deforestation rate for PNG is that reported in the FAO's 2005 Global Forest Review Assessment (FAO, 2005a). In this document the deforestation rate reported for PNG between 2000 and 2005, as well as between 1990 and 2000, is 0.5 percent/yr. Both the 1990-2000 and the 2000-2005 FAO deforestation rates are based on simple linear extrapolation of a previous assessment of forest change between 1975 and 1996, and include no additional information about forest change occurring after 1996 (FAO, 2005b). Furthermore, the FAO deforestation rate is based not only on an estimate of the area of forest cleared between 1975 and 1996, but also an estimate of the area of logged but regenerating forest (FAO, 2005a, b). The 0.5 percent/yr reported in the FAO (2005) Global Forest Review Assessment (FAO, 2005b) is therefore not a deforestation rate but an overall forest change rate, as it includes both deforestation and forest degradation. Thus there are three problems with the 2000-2005 deforestation rate reported by the FAO:

(1) Problems with the original estimate of forest area in 1975 and 1996,

(2) Problems associated with the definition of logged regenerating forest as 'deforested',

(3) Problems associated with linear extrapolation of the 1975-1996 change rate to 2000-2005.

ESTIMATE OF 1975 AND 1996 FOREST AREA – The first problem with the FAO's 2000-2005 and 1990-2000 rates is in the way that forest boundaries in 1975 and 1996 were estimated in the original analysis. The FAO 1975 forest area was estimated from the same set of aerial photographs that we have used (Hammermaster & Saunders, 1995; McAlpine & Quigley, 1998; McAlpine & Freyne, 2001; FAO, 2005b). However, the boundaries between forest and non-forest cover were delineated at too low a resolution for them to be used as a baseline against which processes operating on a fine local scale, such as subsistence agriculture and logging, could be measured. Indeed, testing of these boundaries as a baseline showed that the resulting error was in most places greater than actual change. Although our 1:100,000 1972 land-cover map was created from the same aerial photographs as the FAO-referenced study, it possess a higher resolution delineation of forest boundaries (note that the aerial photographs were captured in the period 1972-1974, with the majority in 1972. We have referred to these as 1972 data, while the FAO-referenced study classified them as 1975 data). This is apparent in Figure 42 in which the boundaries of the FAO-referenced study and the ones used in our study are displayed over the aerial photography used to create them.

The FAO 1996 forest area was generated by visually comparing un-orthorectified hard-copy prints of Landsat TM imagery circa 1994-1996 with the vectors derived from the aerial photography (McAlpine and Quigley, 1998; McAlpine and Freyne, 2001). This resulted in several sources of error: the scale of the 1975 forest boundaries were too coarse to detect fine-scale change; there was considerable spatial error in the un-orthorectified 1996 Landsat imagery; it was difficult to observe local detail on low-resolution prints; and there were inaccuracies in the manual transcription of 'change' areas.

Thus there is considerable uncertainty associated with the estimate of forest change produced by comparing the 1975 and 1996 land-cover maps which were used to calculate the 1990-2000 and 2000-2005 change rates reported by the FAO (FAO, 2005a, b).

INCLUSION OF LOGGED BUT REGENERATING FOREST AS 'DEFORESTED' – The second major problem with the rates reported in the FAO's 2005 Global Forest Review Assessment (FAO, 2005a) is that they were calculated by including an estimate of logged but regenerating forest as 'deforested'. The area of forest reported in the original data source used to produce the FAO deforestation rates (FAO, 2005b) was 33,065,000 ha in 1975, and 31,750,000 ha in 1996, of which 1,985,000 ha were logged but regenerating forest, and 29,765,000 ha were primary forest (McAlpine & Quigley, 1998). When the total area of forest in 1975 is compared with the total area of forest in 1996, this equates to a deforestation rate of 0.2 percent/yr. However, when the area of forest in 1975 is compared with the area of primary forest in 1996, the change rate is 0.5

percent/yr. This overall change rate (0.5%) includes the percentage of forest cleared between 1975 and 1996, as well as the percentage of forest degraded to secondary forest by logging. Therefore, although the change rates for PNG reported by the FAO (FAO, 2005a, b) are described as 'deforestation' rates, they are in fact rates of overall forest change (deforestation and degradation) because logged but regenerating forest has been excluded from the 'forest' category. Comparison of this revised FAO estimate of deforestation (0.2% per year) and overall change (0.5% per year) with our own recent estimates of deforestation (0.77% per year, see Table 6) and overall change (1.41% per year, see Table 6) highlights the substantial underestimation of the extent and rate of recent deforestation and forest degradation by previously reported deforestation estimates.

LINEAR EXTRAPOLATION OF THE 1975-1996 CHANGE RATE TO 2000-2005 – The third major problem with the FAO estimate of the 2000-2005 'deforestation' rate, is that it was calculated by linearly extrapolating the 1975-1996 'deforestation' rate discussed above out to 2000-2005, a period not covered by the original analysis (McAlpine & Quigley, 1998; McAlpine & Freyne, 2001). Extrapolating the 1975-1996 rate out to 2000-2005 ignores the substantial increase in logging activity that has occurred in PNG's forests since 1996 (Figure 7). The FAO 2000-2005 rate also does not account for the probable increase in subsistence-related clearance associated with the continued rapid increase in the population after 1996 (Figure 13). Similarly, the FAO 2000-2005 rate does not include the large areas of deforestation that occurred as a consequence of the 1997-1998 El Niño-related fires.

SUMMARY – Thus the FAO (1990-2000) and FAO (2000-2005) 'deforestation' rates (FAO, 2005a, b) are in fact the long-term average annual 1975-1996 overall forest change rate, published in its original form by McAlpine & Quigley (1998), and later, by McAlpine & Freyne (2001). Furthermore, this long-term average annual 1975-1996 forest change rate was derived from data sources created at too coarse a scale to adequately detect fine-scale change such as that occurring as a result of subsistence agricultural and logging expansion.

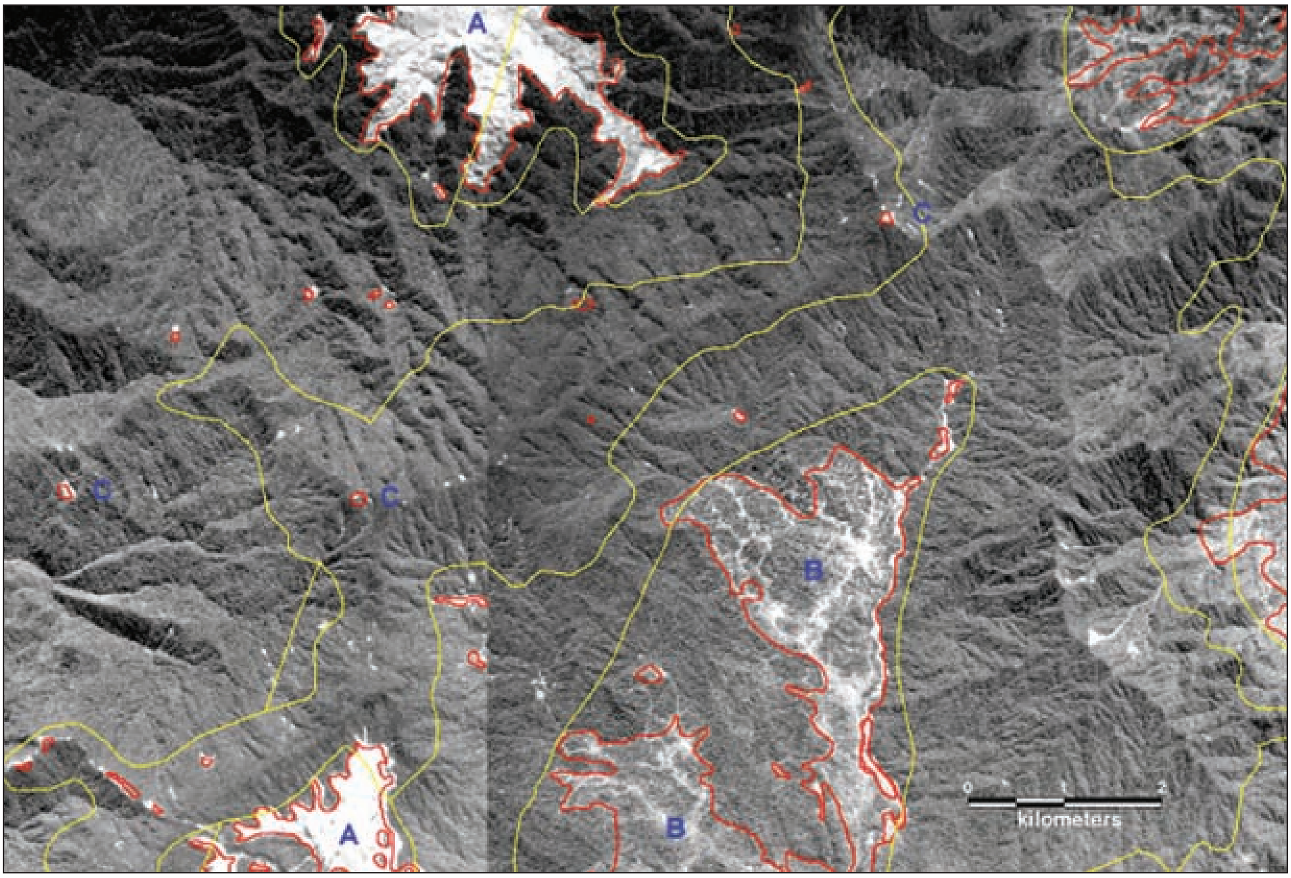
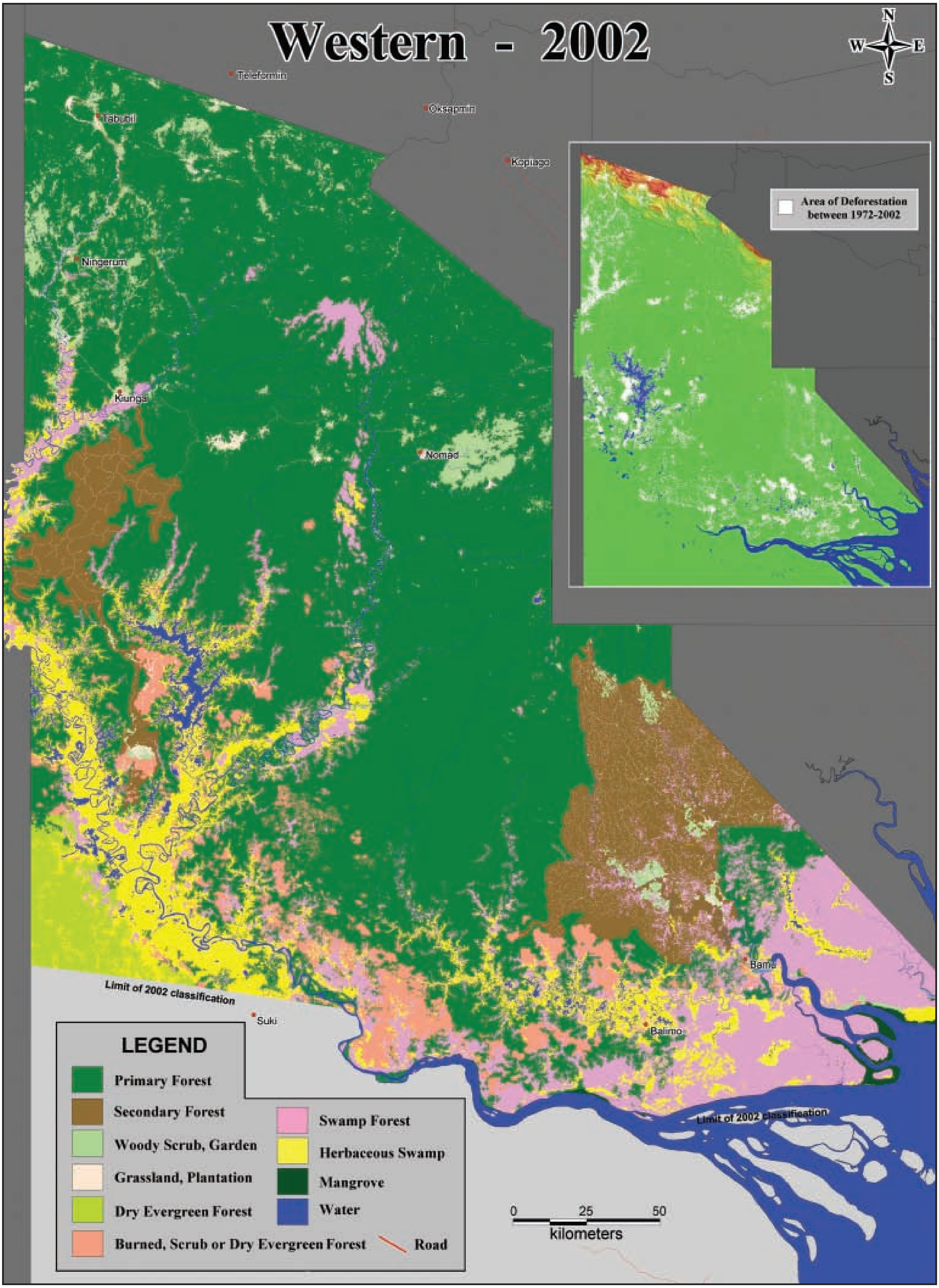


Figure 42: Located approximately 10km to the west of Goroka township, this plate shows a mosaic of orthorectified 1972 aerial photography overlain with the 1972 T601 forest boundaries used in the UPNG study (red boundaries, Coulthard-Clark, 2000) and the forest boundaries used to estimate the FAO forest change rate (yellow boundaries, Hammermaster and Saunders, 1995). Of note is the accurate delineation of the areas of Sub-alpine Grassland (**A**) by the T601 boundaries, compared with the FAO (1975) forest boundaries that are 'out' to the order of up to a kilometre. In the central-southern region, an area of intensive logging can be seen (**B**). The T601 boundaries accurately delineate and record this area secondary growth. The FAO (1975) boundary for this area is less inaccurate. Note also the small areas of grassland that are captured in the T601 data (**C**). The slight mismatch between some of the T601 grassland boundaries and the backdrop photography is a consequence of both the difficulty of orthorectifying the photography coupled with the stereoscope error in the most rugged terrain in PNG.

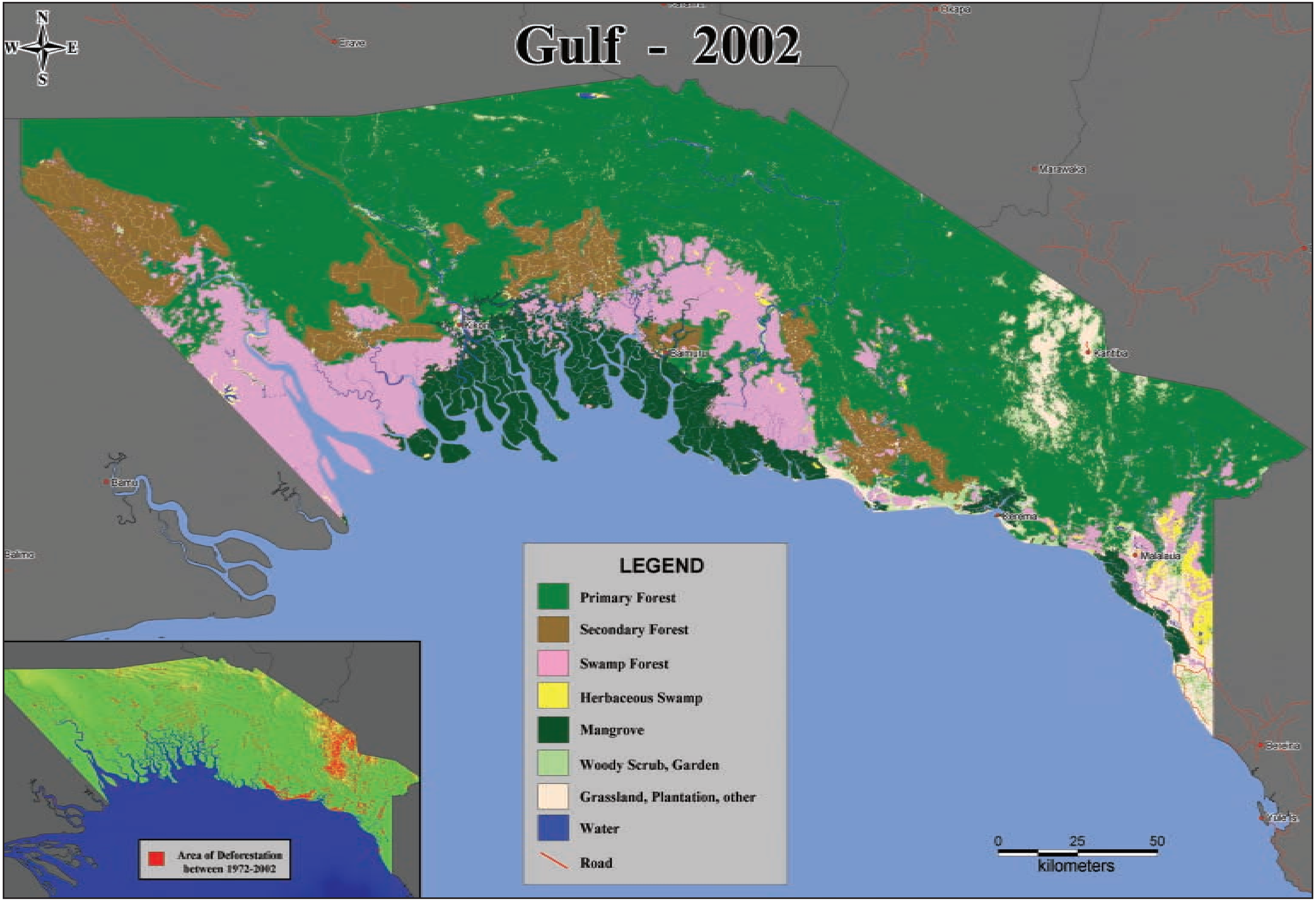
Annex 4 – Provincial Maps

The maps show the 2002 land-cover classification, as well as areas deforested and degraded in each Province. They are presented in the following order:

- Western
- Gulf
- Central
- Milne Bay
- Oro
- Southern Highlands
- Enga
- Western Highlands, Chimbu and Eastern Highlands
- Morobe
- Madang
- East Sepik
- West Sepik
- Manus
- New Ireland
- East New Britain
- West New Britain
- Bougainville

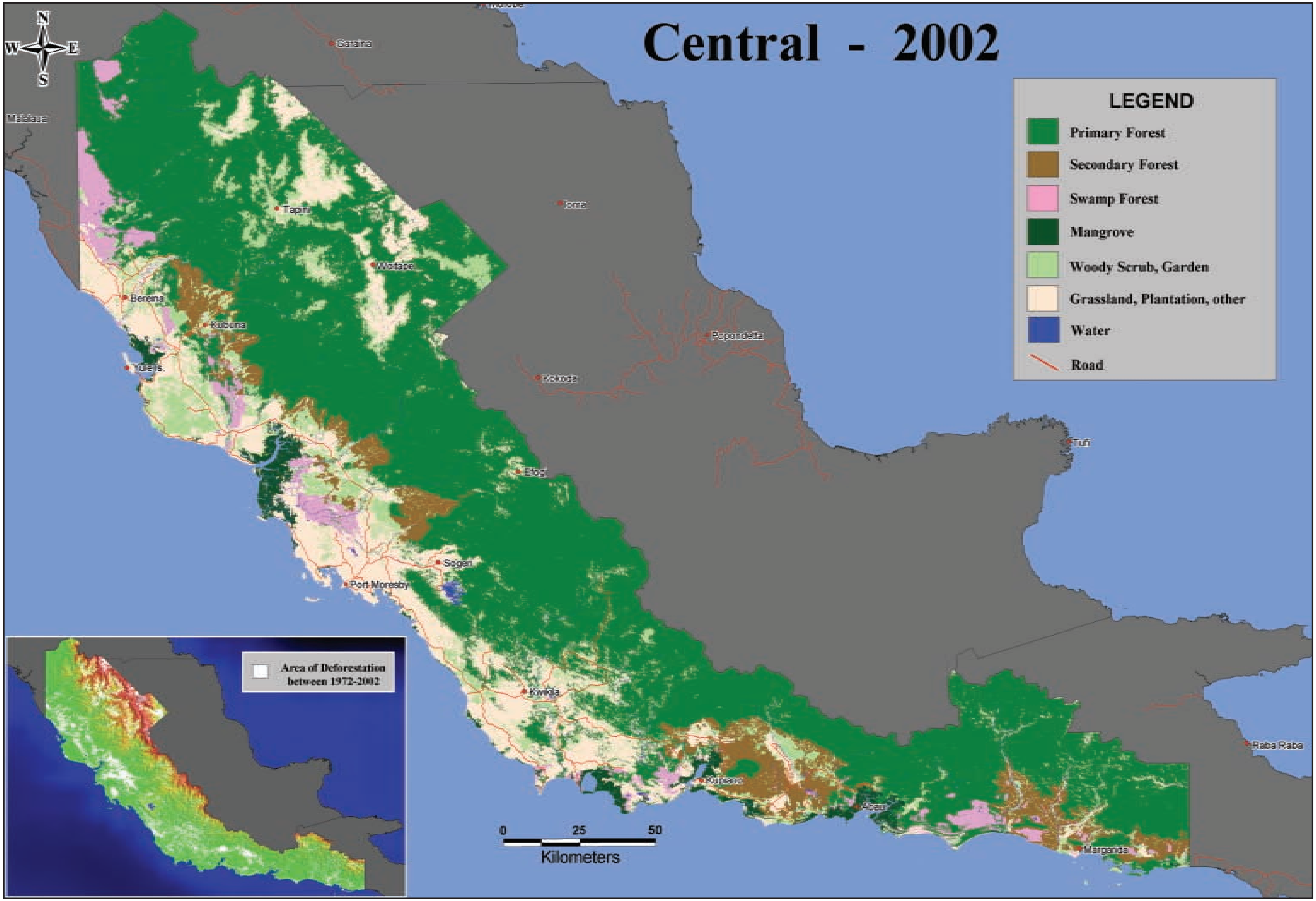


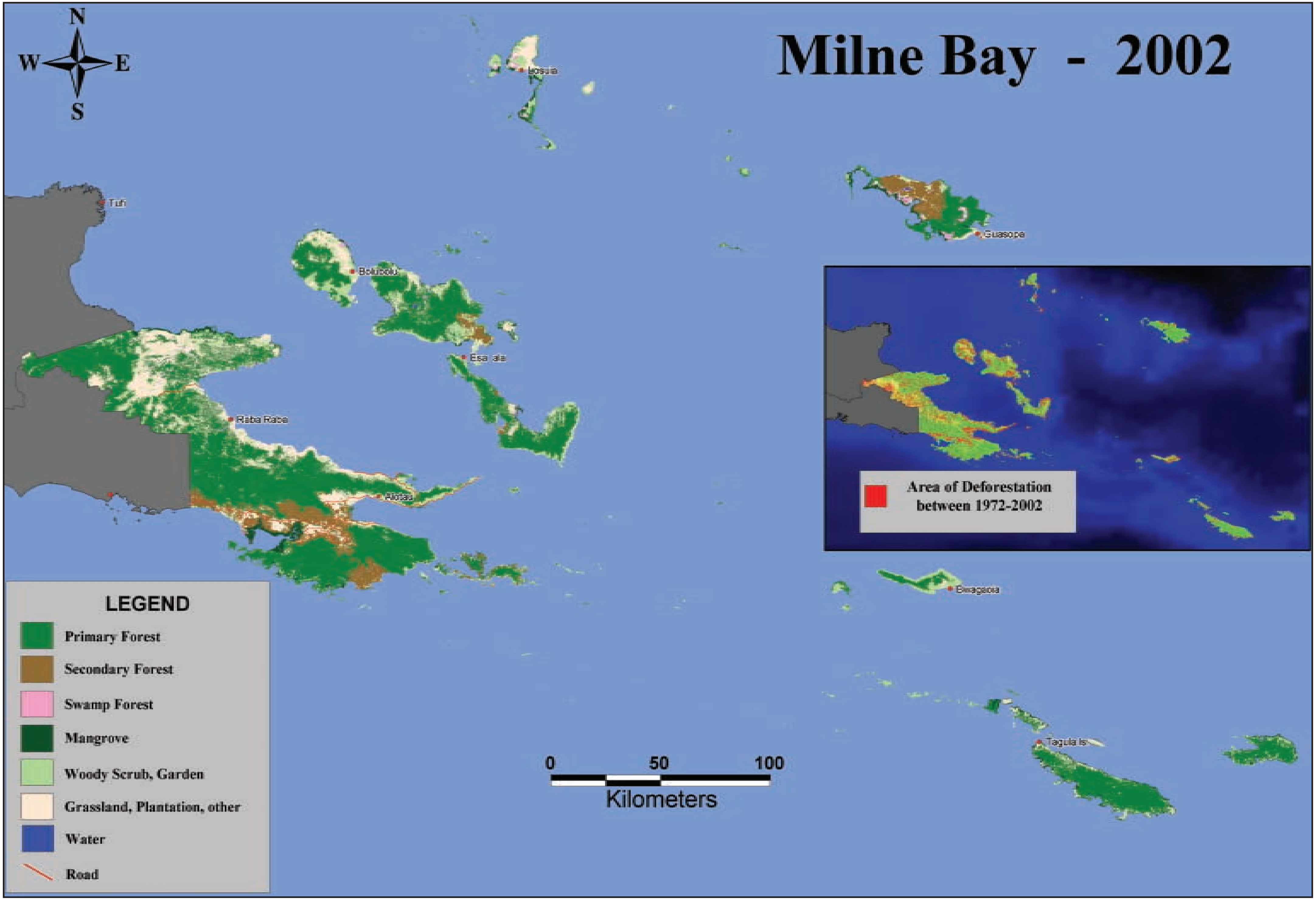
Western - 2002
N
W
E
S
Telefomin
Oksapmin
Kopiago
Tabubil
Ningerum
Kiunga
Nomad
Area of Deforestation between 1972-2002
Bamu
Balimo
Suki
Limit of 2002 classification
Limit of 2002 classification
LEGEND
Primary Forest
Secondary Forest
Woody Scrub, Garden
Grassland, Plantation
Dry Evergreen Forest
Burned, Scrub or Dry Evergreen Forest
Swamp Forest
Herbaceous Swamp
Mangrove
Water
Road
0
25
50
kilometers

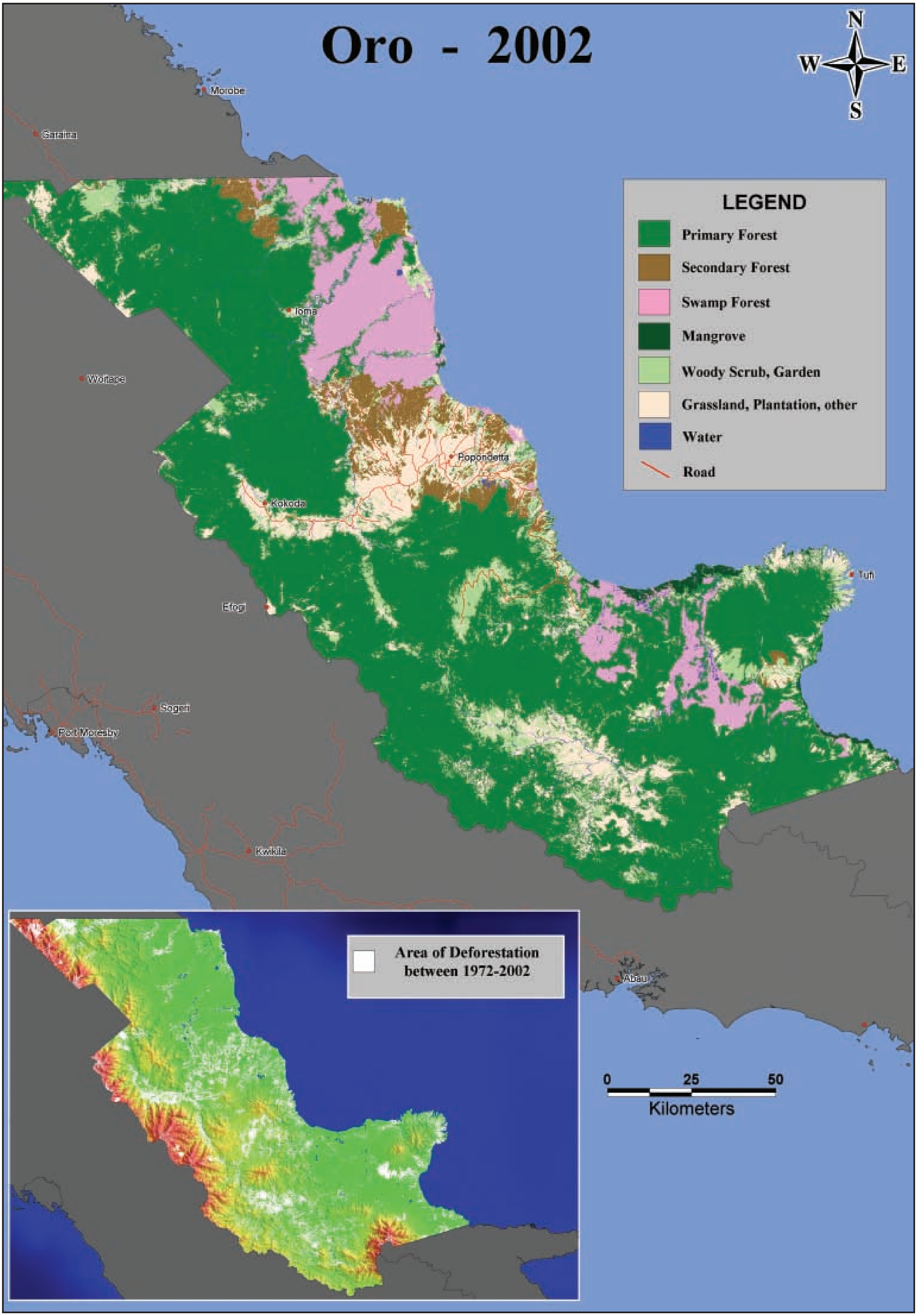


Gulf - 2002
N
W
E
S
Erave
Okapa
Marawaka
Kikori
Baimuru
Kantiba
Kerema
Malalaua
Bereina
Yule Is.
Bamu
Balimo
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Herbaceous Swamp
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
0
25
50
kilometers
Area of Deforestation between 1972-2002

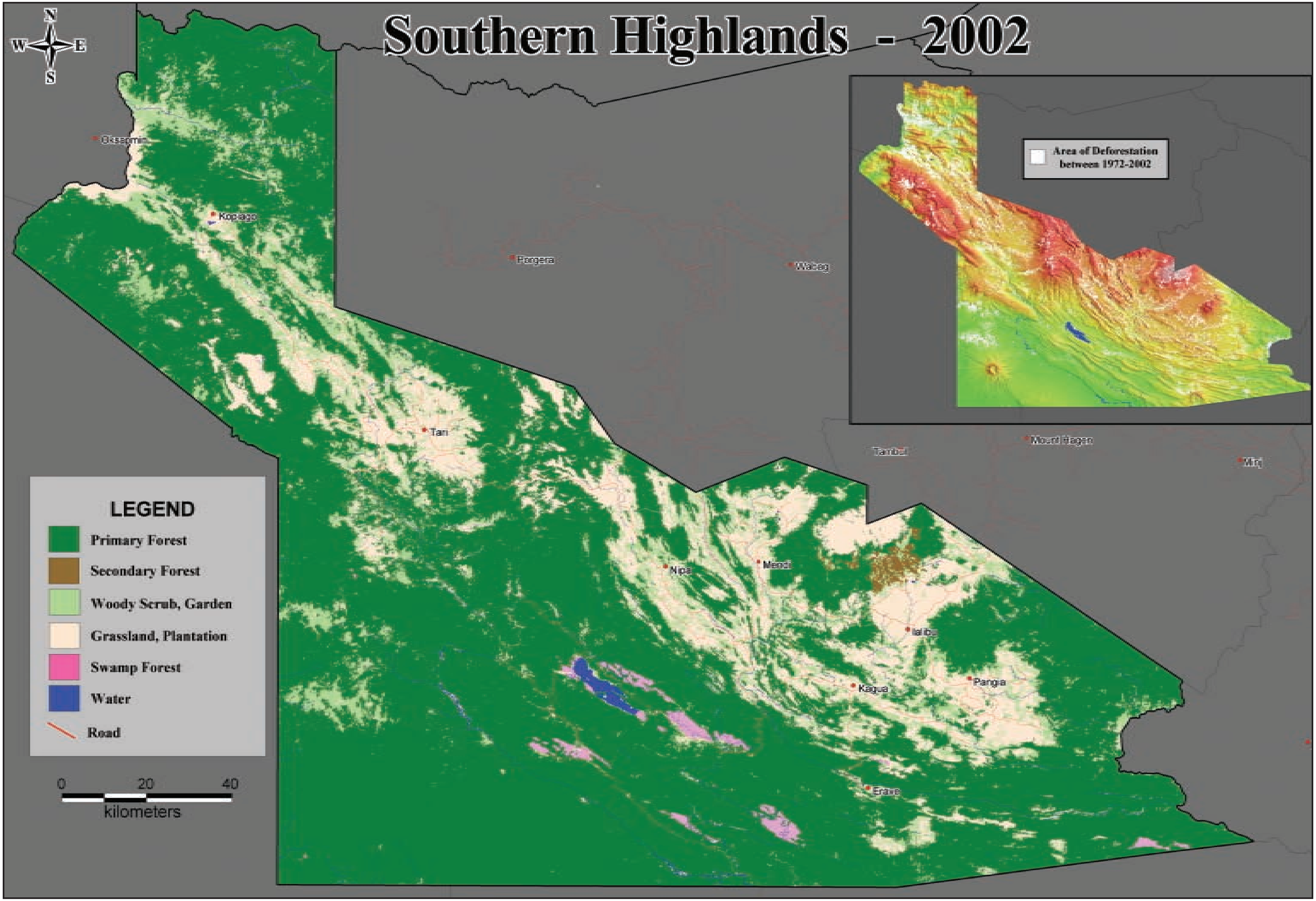
Central - 2002




Milne Bay - 2002
N
W
E
S
Tufi
Losuia
Guasope
Bolubolu
Esa'ala
Raba Raba
Alotau
Bwagaoia
Tagula Is
Area of Deforestation between 1972-2002
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
0
50
100
Kilometers

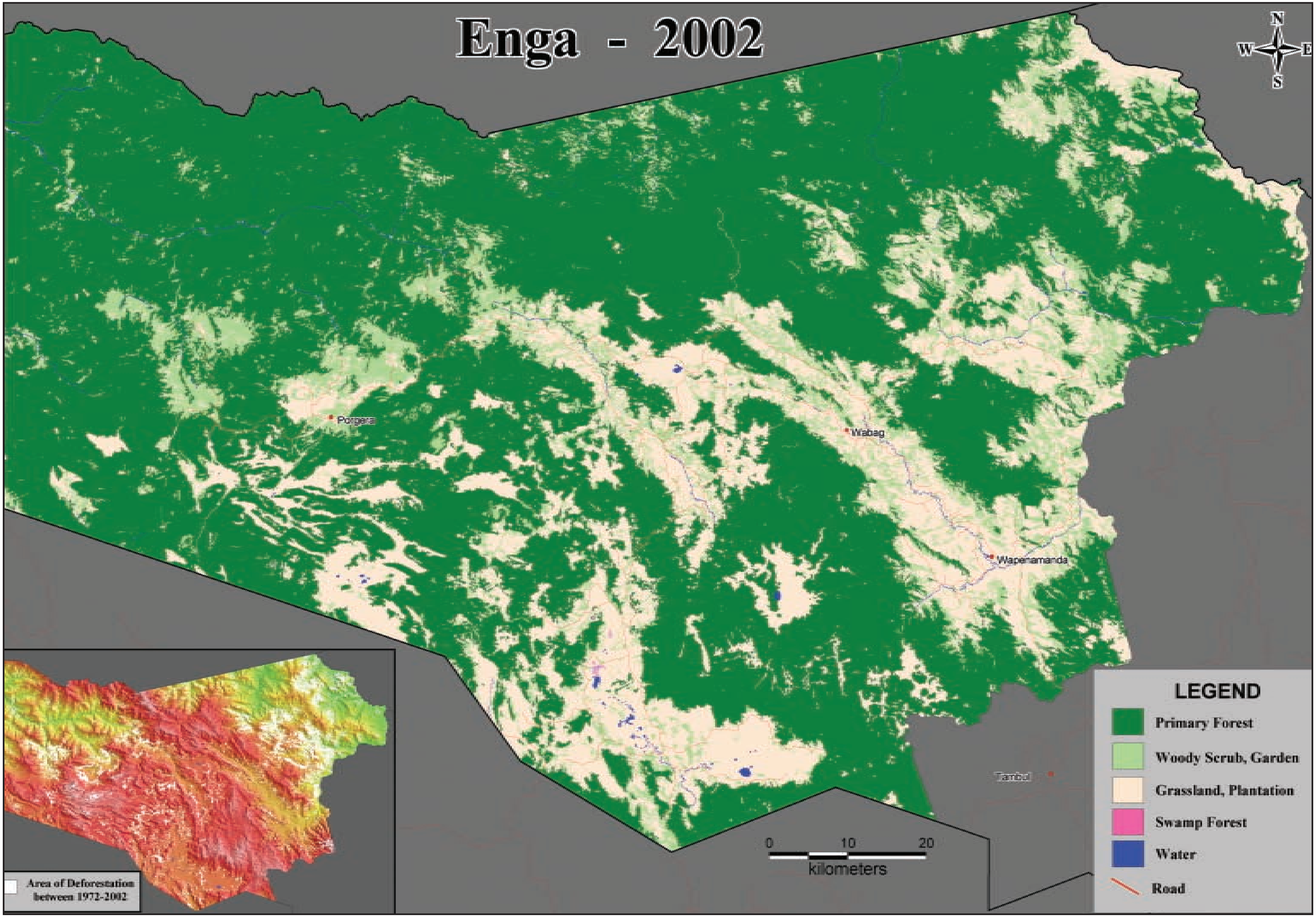


Oro - 2002
N
W
E
S
Morobe
Garaina
Ioma
Woitape
Popondetta
Kokoda
Efogi
Tufi
Sogeri
Port Moresby
Kwikila
Abau
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
Area of Deforestation between 1972-2002
0
25
50
Kilometers

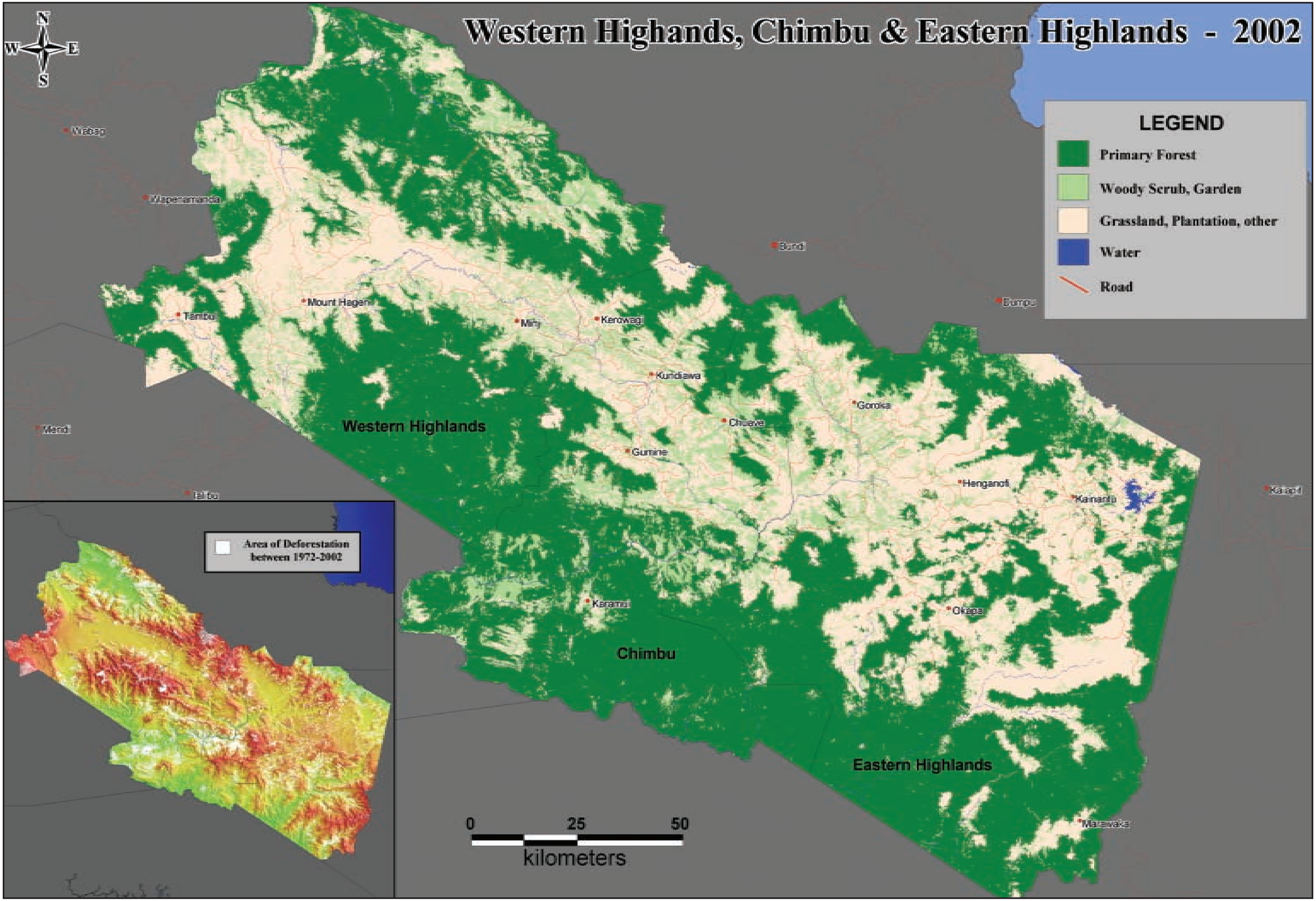


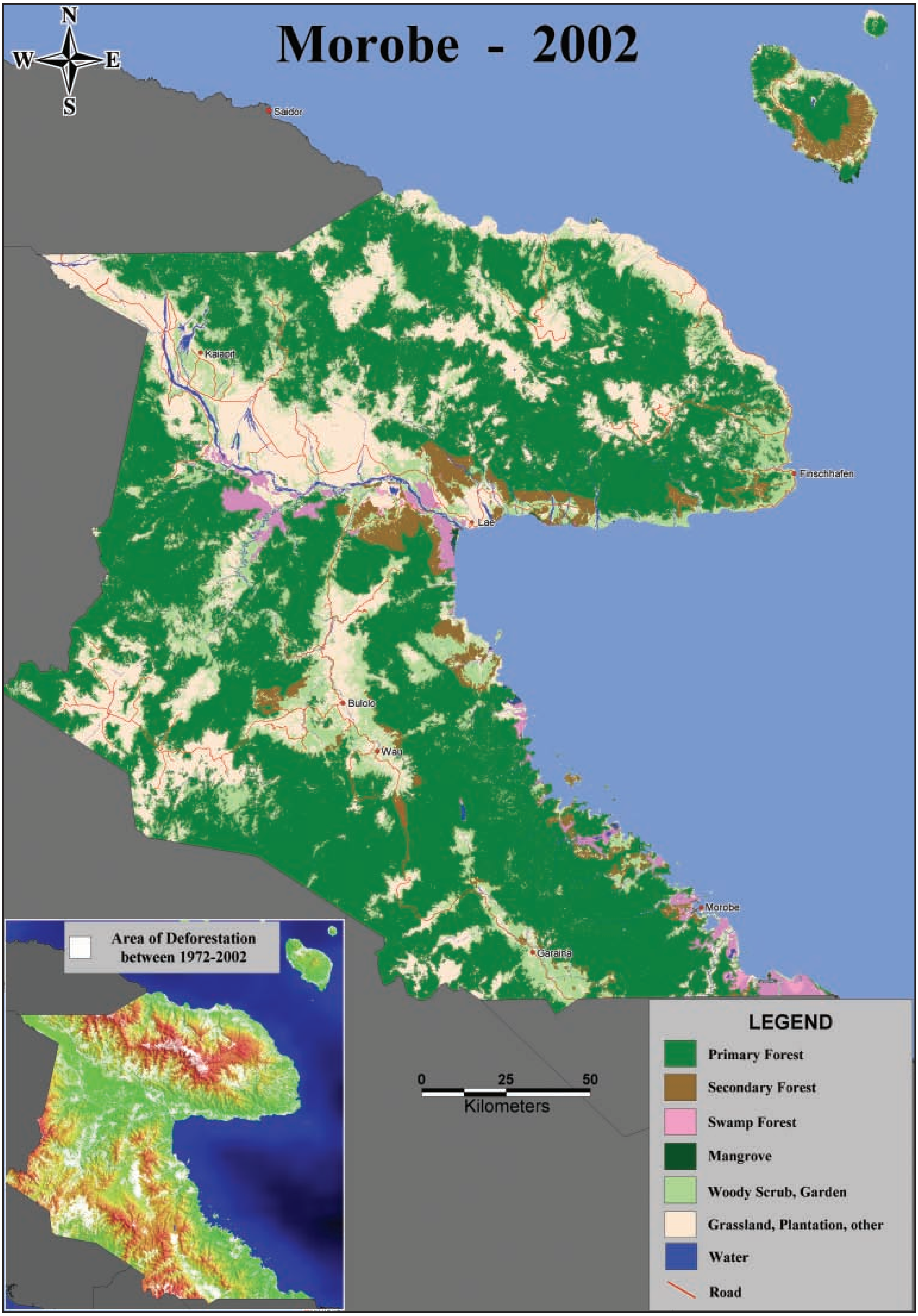
Southern Highlands - 2002
N
W
E
S
Area of Deforestation between 1972-2002
Oksapmin
Kopiago
Porgera
Wabag
Tari
Tambul
Mount Hagen
Minj
Nipa
Mendi
Ialibu
Kagua
Pangia
Erave
LEGEND
Primary Forest
Secondary Forest
Woody Scrub, Garden
Grassland, Plantation
Swamp Forest
Water
Road
0
20
40
kilometers

Enga - 2002

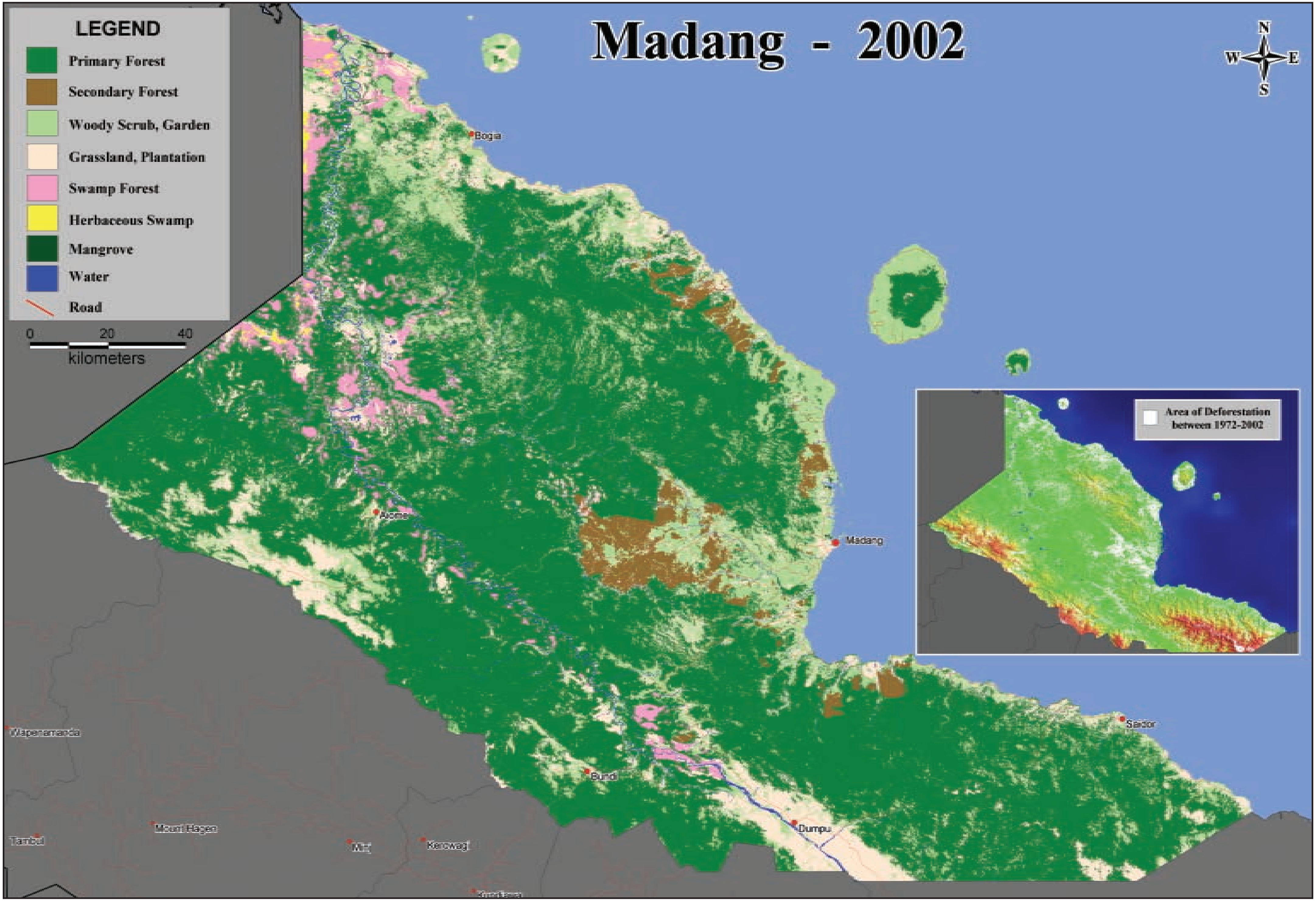


N
W
E
S
Porgera
Wabag
Wapenamanda
Tambul
LEGEND
Primary Forest
Woody Scrub, Garden
Grassland, Plantation
Swamp Forest
Water
Road
0
10
20
kilometers
Area of Deforestation between 1972-2002

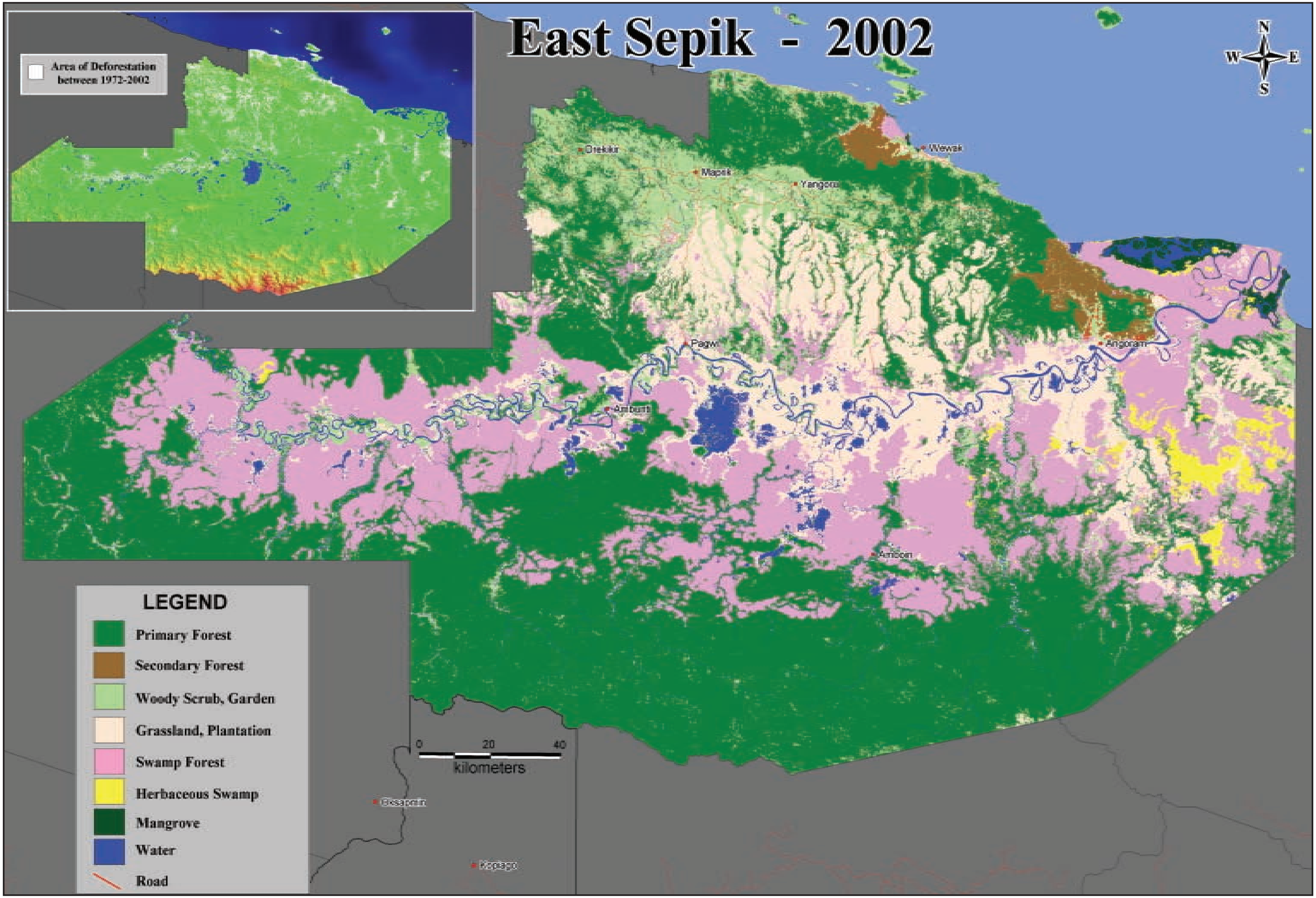

Western Highands, Chimbu & Eastern Highlands - 2002
LEGEND
Primary Forest
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
N
W
E
S
Wabag
Wapenamanda
Mount Hagen
Tambul
Mendi
Ialibu
Minj
Kerowagi
Kundiawa
Chuave
Gumine
Goroka
Bundi
Bumpu
Henganofi
Kainantu
Kalapit
Okapa
Marawaka
Karamui
Western Highlands
Chimbu
Eastern Highlands
0
25
50
kilometers
Area of Deforestation between 1972-2002

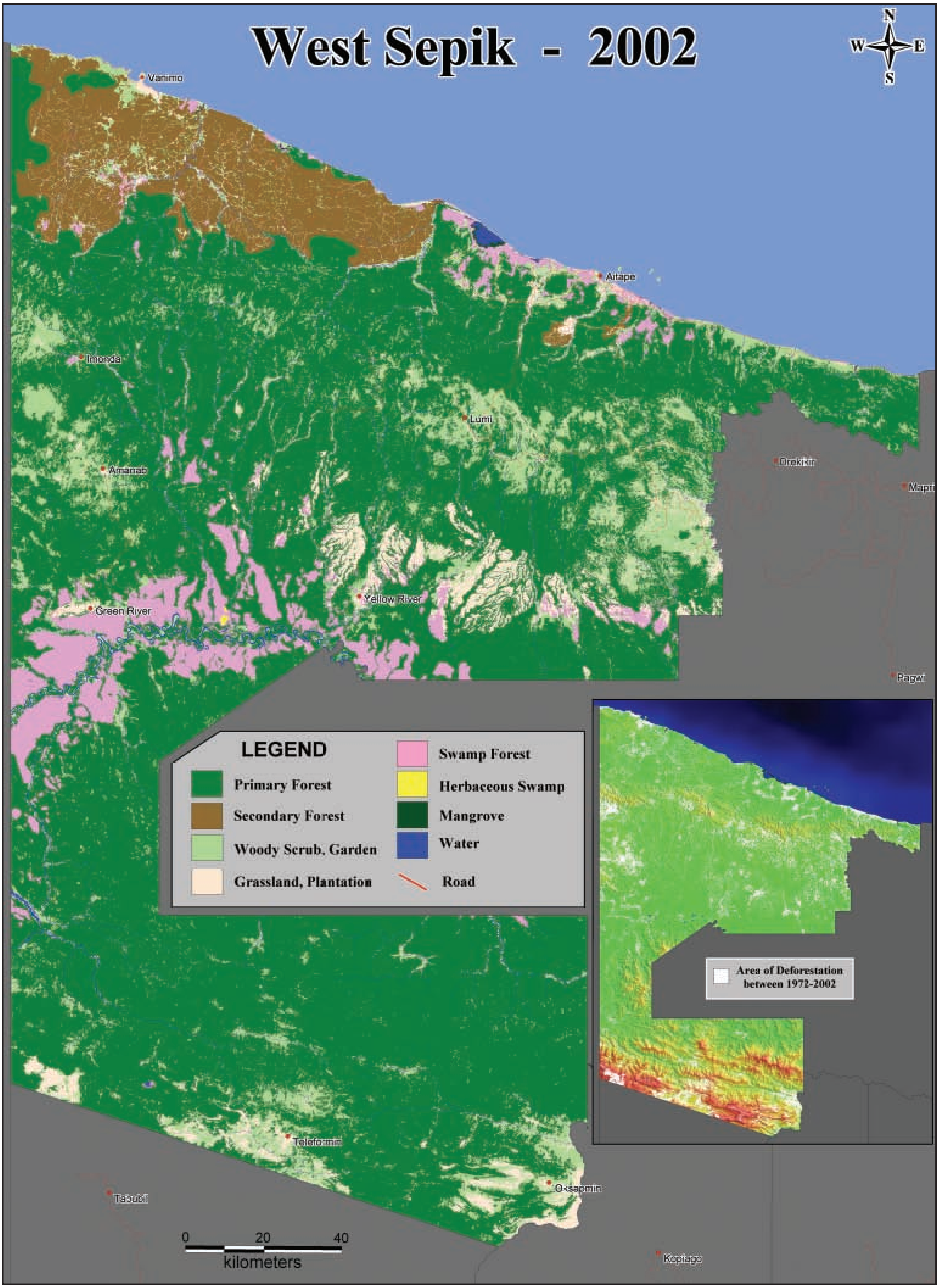


Morobe - 2002
N
S
E
W
Saidor
Kaiapit
Finschhafen
Lae
Bulolo
Wau
Morobe
Garaina
Area of Deforestation between 1972-2002
0
25
50
Kilometers
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road

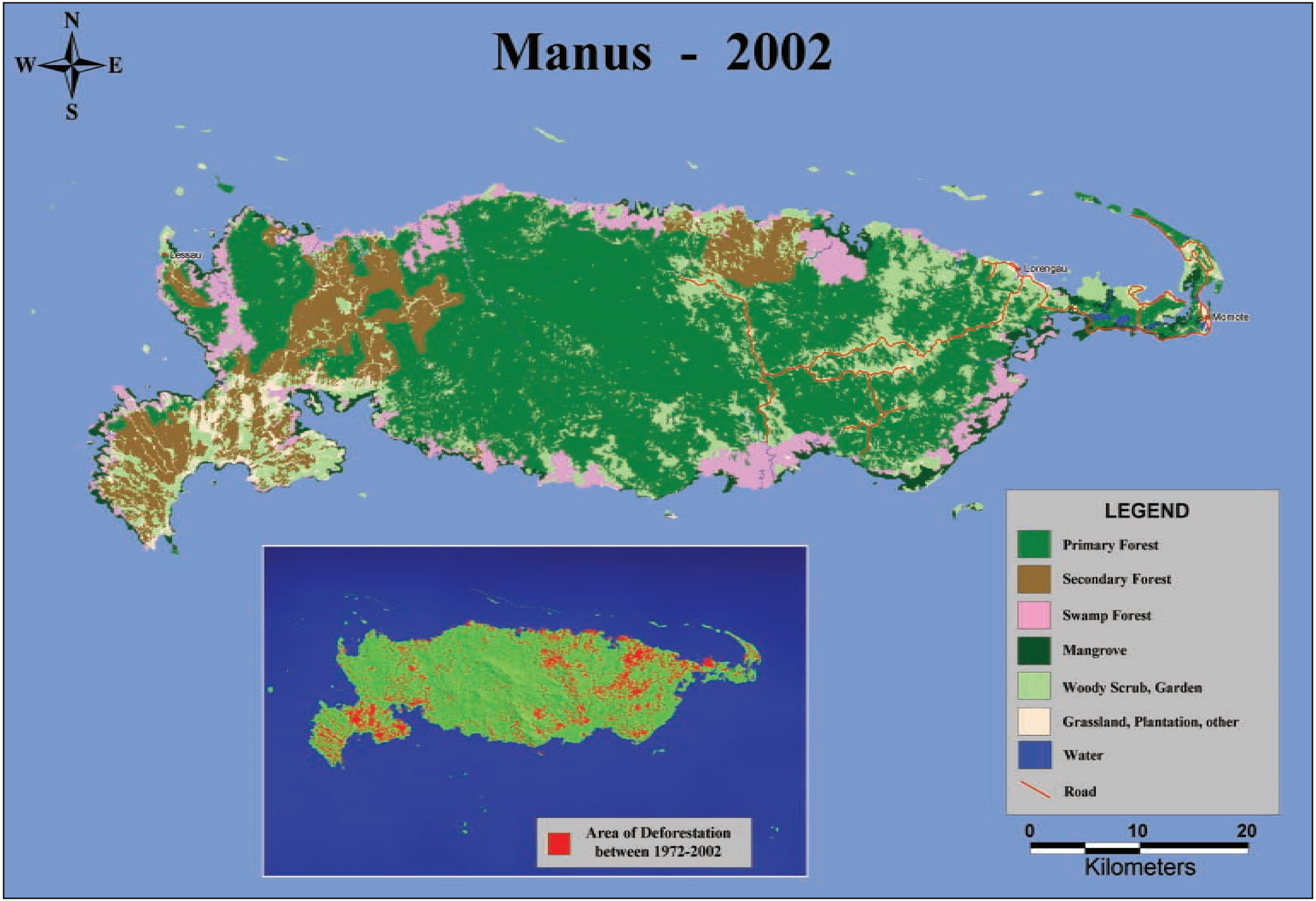


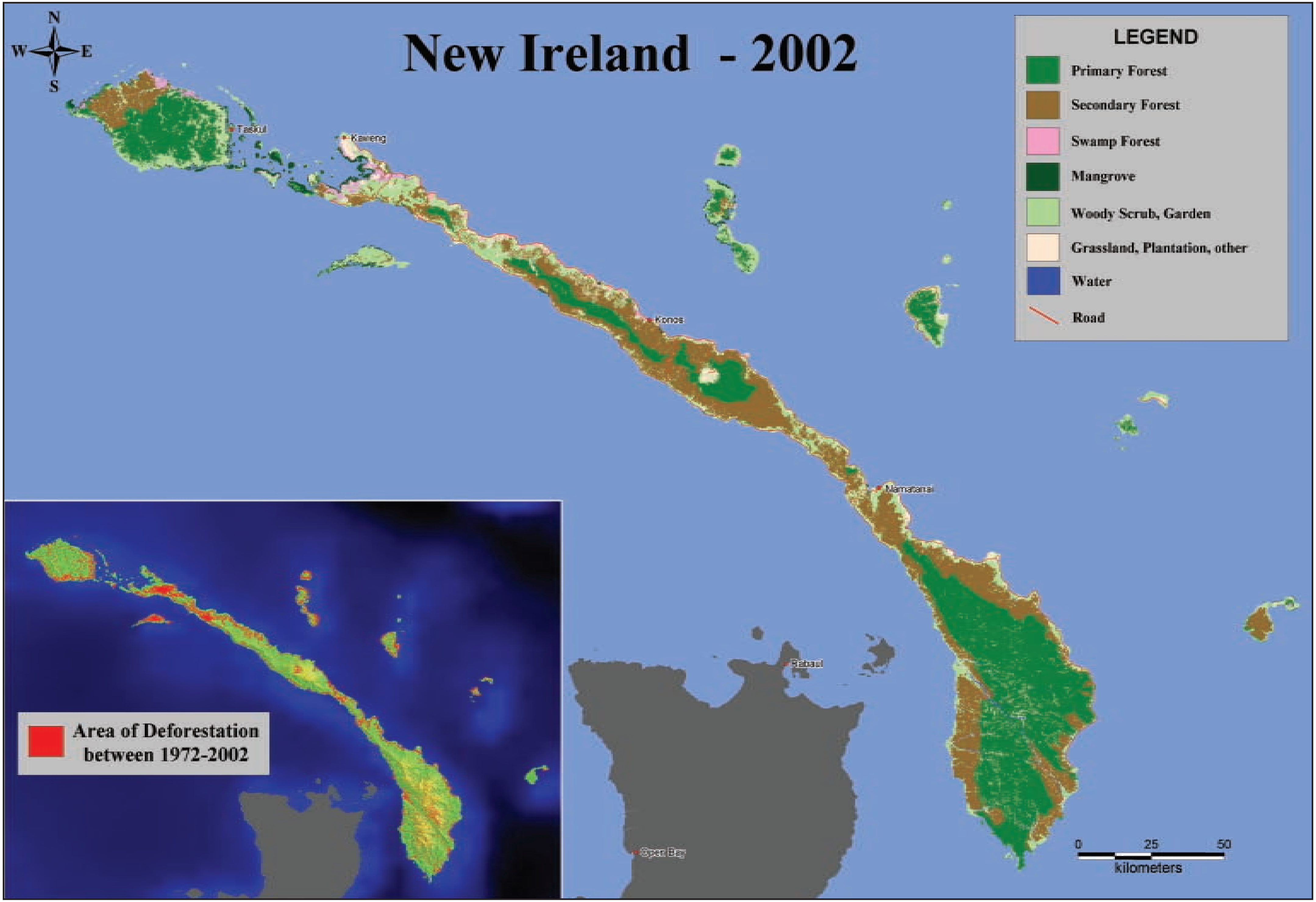
Madang - 2002
LEGEND
Primary Forest
Secondary Forest
Woody Scrub, Garden
Grassland, Plantation
Swamp Forest
Herbaceous Swamp
Mangrove
Water
Road
0
20
40
kilometers
N
W
E
S
Bogia
Madang
Aiome
Bundi
Dumpu
Saidor
Wapenamanda
Mount Hagen
Tambul
Minj
Kerowagi
Area of Deforestation between 1972-2002


East Sepik - 2002
N
W
E
S
Area of Deforestation between 1972-2002
Dreikikir
Maprik
Yangoru
Wewak
Pagwi
Angoram
Ambunti
Amboin
Oksapmin
Kopiago
0
20
40
kilometers
LEGEND
Primary Forest
Secondary Forest
Woody Scrub, Garden
Grassland, Plantation
Swamp Forest
Herbaceous Swamp
Mangrove
Water
Road

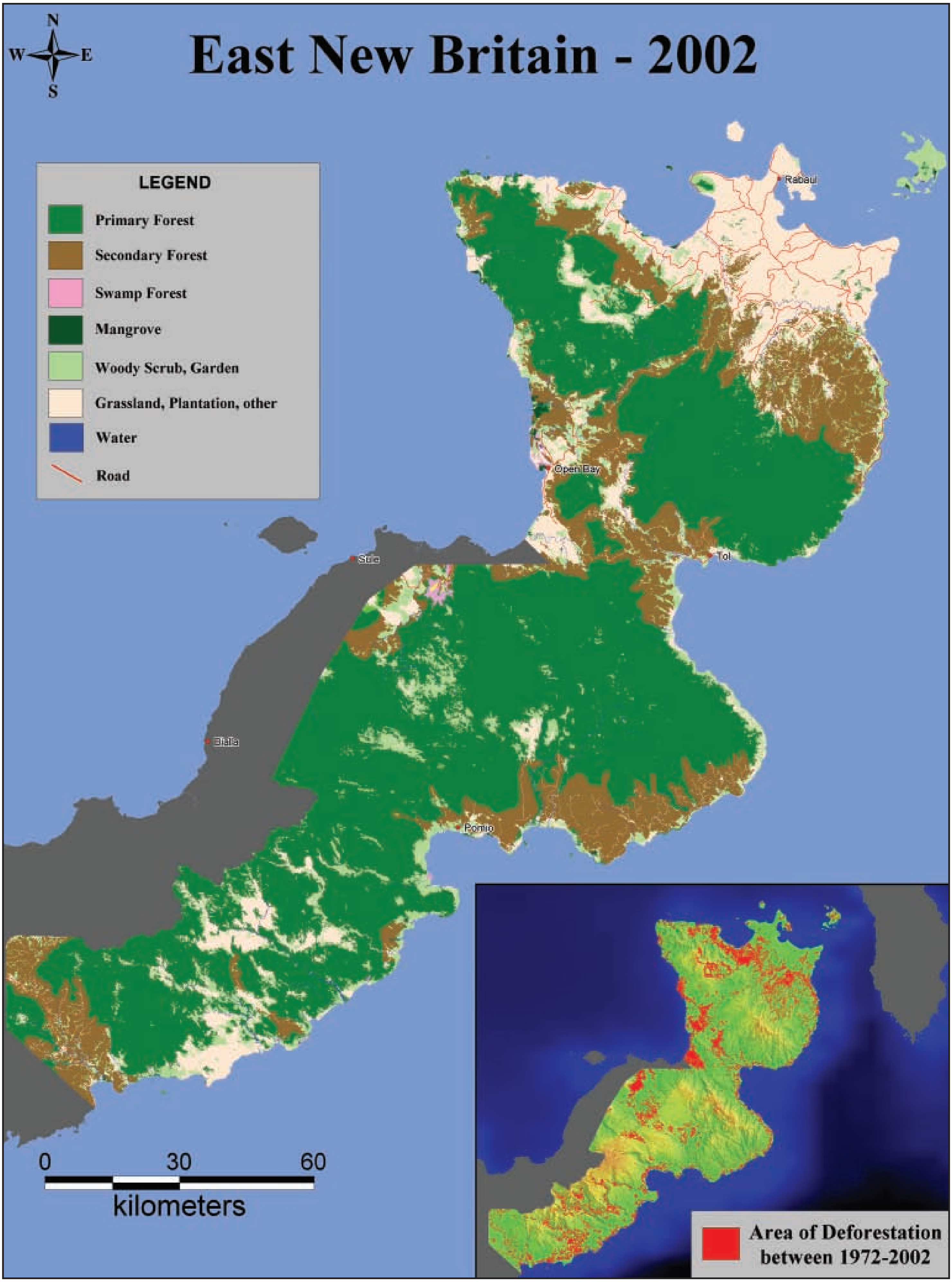


West Sepik - 2002
N
W
E
S
Vanimo
Aitape
Imonda
Lumi
Amanab
Drekikir
Maprik
Yellow River
Green River
Pagwi
LEGEND
Primary Forest
Secondary Forest
Woody Scrub, Garden
Grassland, Plantation
Swamp Forest
Herbaceous Swamp
Mangrove
Water
Road
Area of Deforestation between 1972-2002
Telefomin
Tabubil
Oksapmin
Kopiago
0
20
40
kilometers

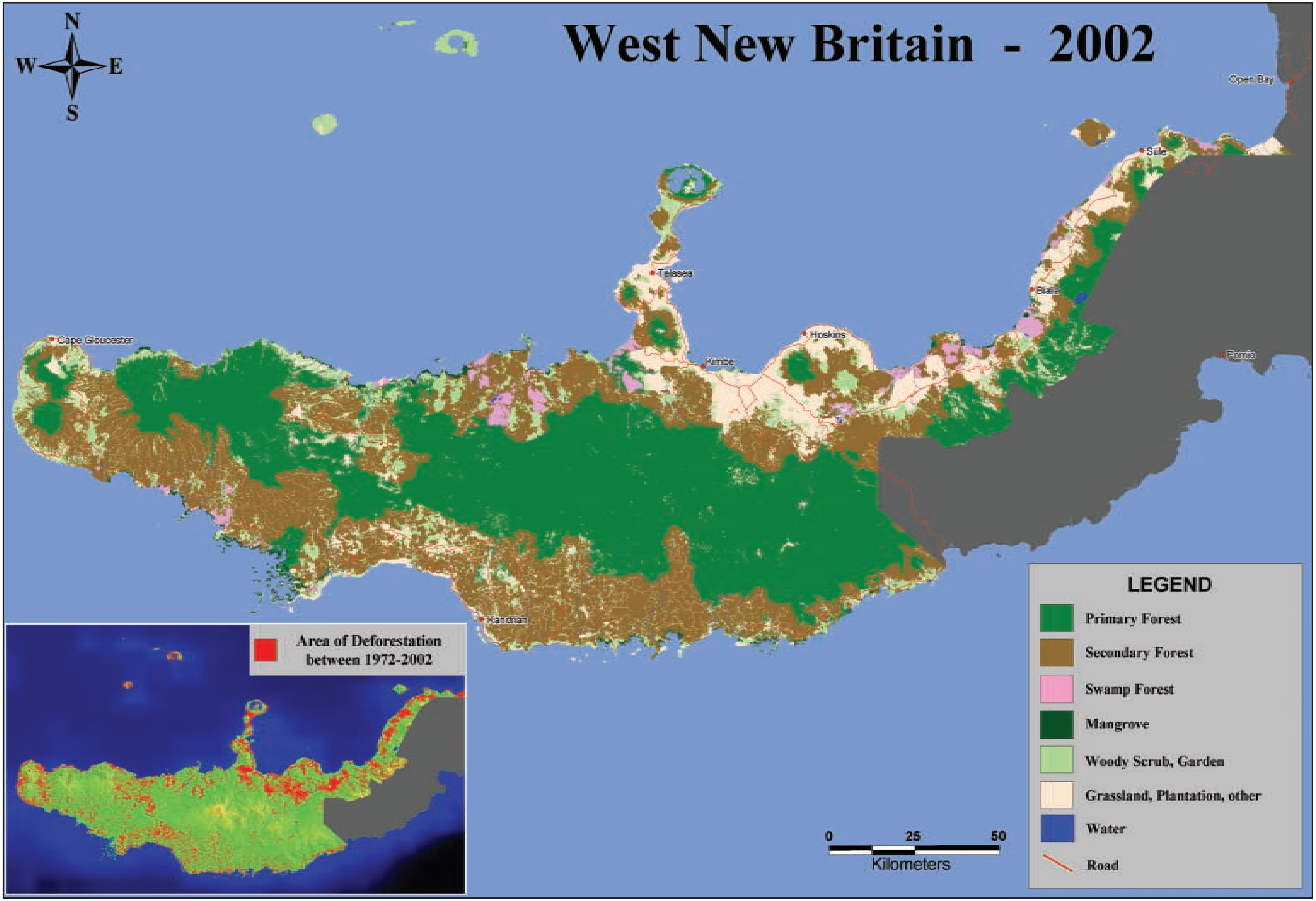

Manus - 2002
N
W
E
S
Lessau
Lorengau
Momote
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
0
10
20
Kilometers
Area of Deforestation between 1972-2002

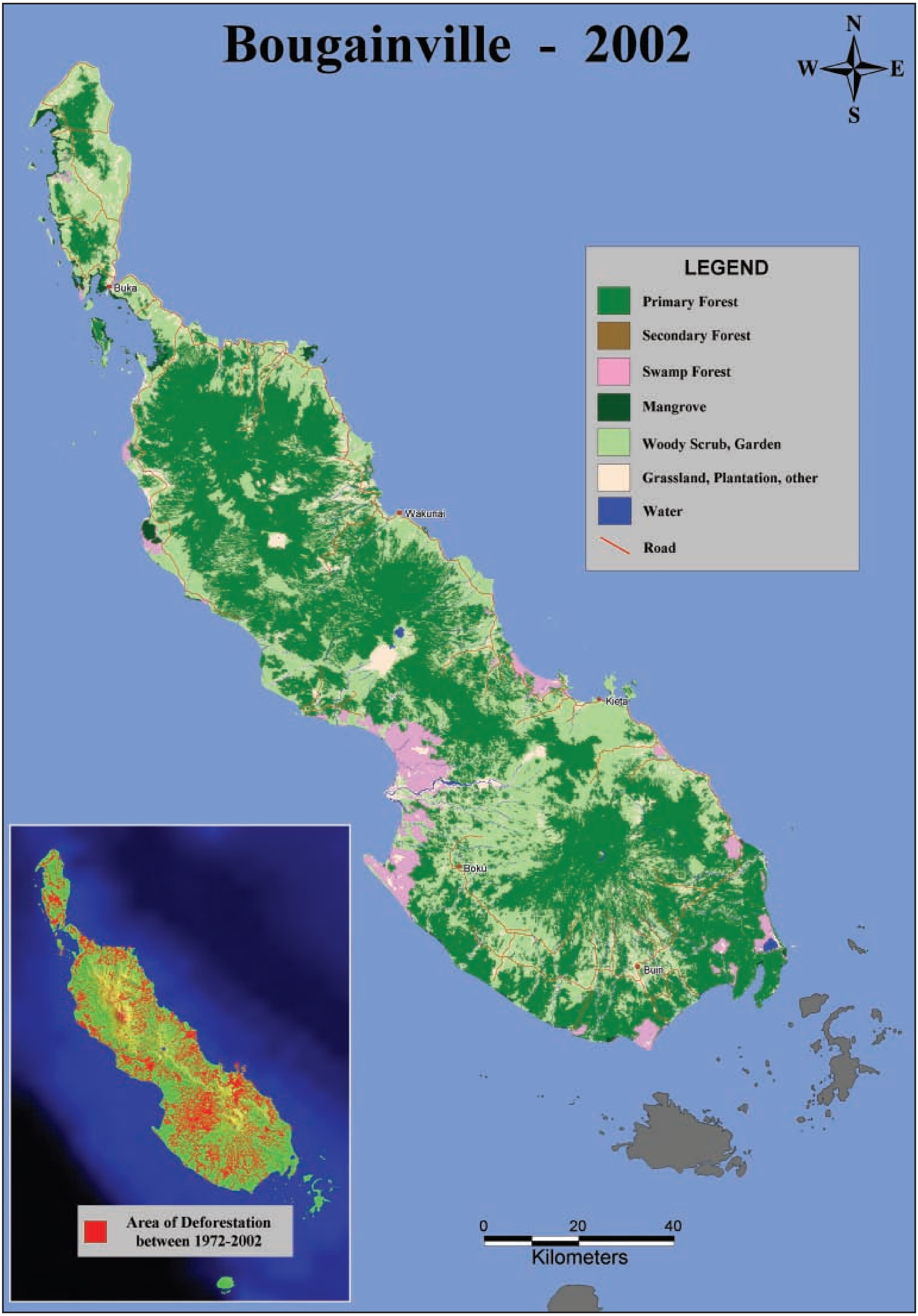


New Ireland - 2002
N
W
E
S
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
Taskul
Kaveng
Konos
Namatanai
Rabaul
Open Bay
0
25
50
kilometers
Area of Deforestation between 1972-2002



East New Britain - 2002
N
S
W
E
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
Rabaul
Open Bay
Tol
Pomio
0
30
60
kilometers
Area of Deforestation between 1972-2002


West New Britain - 2002
N
W
E
S
Open Bay
Sule
Bialla
Pomio
Talasea
Hoskins
Kimbe
Cape Gloucester
Kandrian
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
0
25
50
Kilometers
Area of Deforestation between 1972-2002



Bougainville - 2002
N
W
E
S
LEGEND
Primary Forest
Secondary Forest
Swamp Forest
Mangrove
Woody Scrub, Garden
Grassland, Plantation, other
Water
Road
Buka
Wakunai
Kieta
Boku
Buin
Area of Deforestation between 1972-2002
0
20
40
Kilometers

Annex 5 - Glossary

Cover and Coverage: Geographic data set that represents the spatial distribution of a specific type of feature (e.g., forest coverage): often simply called a layer. ARC/INFO (ESRI, 2005) also has a data format that is referred to as a coverage: one of a series of data themes, such as wetlands or water lines, in a geographic information system (q.v.) with graphic and attribute data related to that topic.

CSIRO: The Australian Commonwealth Science and Industrial Research Organisation. This organisation conducted regional surveys and assessments of the natural resources of PNG, especially in the decade leading up to Independence in 1975.

Deforestation: Deforestation is the replacement of forest (q.v.) with other land-cover types including subsistence gardens, plantations, grassland, or scrub. Such replacement may be persistent or, after many decades, lead to re-establishment of forest by the process of succession. However, an area deforested since 1972 will have had insufficient time to revert to forest by 2002.

Degradation: The process of conversion of primary or climax forest into secondary forest through commercial logging. Degradation through commercial logging includes felling trees for timber and associated uses (ramps, roads, bridges, wharves, etc), associated damage to adjacent forest, vehicle access tracks to extract timber, haulage roads, wharves, areas cleared for log storage, and other infrastructure. An area of forest degraded since 1972 will have had insufficient time to revert to primary forest by 2002.

DIGO: Australian Defence Imagery and Geospatial Organisation. This organization replaced the Royal Australian Survey Corps.

DEM: Digital Elevation Model. A digital representation of continuous altitudinal variation in topography over space. A DEM, such as that used in this thesis, accurately incorporates major ridges and imposes descending drainage lines (i.e. rivers cannot flow uphill), and provides a means to estimate slopes and aspect. A DEM is a pre-requisite for accurately projecting satellite imagery onto a land surface.

ERDAS: ERDAS IMAGINE is a suite of software tools designed specifically to process geospatial imagery (ERDAS, 1999).

ESRI: A suite of software tools primarily designed to process vectors and coverages. It was created by Environmental Systems Research Institute Ltd (ESRI, 2005).

ETM: Landsat Enhanced Thematic Mapper.

Forest: A forest in PNG (q.v.) is here defined as natural (not plantation) woody vegetation that in a climax state has contiguous largely evergreen tree canopies (generally exceeding 85% cover) and a canopy height (m) above [45 – 0.011 (altitude, m)]. Only 2-5% of daylight penetrates the canopy to the ground (reaching 5-20% in gaps) so humidity is usually very high and these forests are of low flammability except after disturbance or prolonged drought: however, these forests are severely damaged by fire. Forest structure and composition vary regionally and with topography, climate, geology and past disturbance. These forests comprise a great variety of tree species and stands are typically mixed in composition and age structure, with angiosperm species surviving to 150-650 years, and gymnosperms to 300-1100 years. These forests are also known as tropical rainforest (including montane, cloud, and moss forest) and are distinguished from (i) less humid fire prone open-sclerophyll forest, woodland and savanna, and (ii) saline mangrove or freshwater swamp vegetation in which the ground is waterlogged for much of the year. Virtually all commercial logging in PNG is within forest as defined here.

FIMS: Forest Inventory Mapping System (Hammermaster and Saunders, 1995).

FRA, FRA 2000, FRA 2005: FAO Global Forest Resource Assessments, with the year of assessment indicated.

Geographic Information System (GIS): A GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that are part of the system.

Geometric rectification: a process by which the geometry of the image area is made planimetric: projected to correctly fit the geographic co-ordinates of a sea-level surface.

GIS: see Geographic Information System.

Ground Control Point (GCP): a point on the Earth's surface where both the image coordinates (latitude and longitude) and map coordinates can be aligned and the image rectified.

ITTO: International Tropical Timber Organisation.

Layer: see Coverage.

MODIS: Moderate Resolution Imaging Spectroradiometer.

MSS: Landsat Multispectral Scanner.

NFA: National Forest Authority.

Orthorectification: Orthorectification is the process by which the geometric distortions of the image are modelled and accounted for, resulting in a planimetricaly correct image. A form of rectification that corrects for terrain displacement using a DEM (q.v.).

Pixel: the smallest spatial digital element which comprises the image data set. Pixels are generally arranged as a rectangular grid.

PNG: Papua New Guinea, the independent nation, created in 1975, that united the former Australian territories of Papua and New Guinea. Papua New Guinea comprises the eastern part of the island of New Guinea and adjacent islands.

Polygon: a closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique. The shape corresponds to a real-world object and is classified as such, e.g. a 'lake'. A contiguous group of pixels that have the same classification (e.g. as 'Forest') can be grouped and vectorised to form a polygon.

Primary tropical forest: Forest (q.v.) that has not been extensively disturbed for centuries and (at a sufficient area) has reached demographic and compositional equilibrium (also known as Climax Forest). Primary forests typically possess a contiguous canopy of slow-growing, shade-tolerant tree species. At low elevations these forests typically include some very large trees that have high trunk wood volume. Such forest has not been commercially logged but is the main target for timber extraction.

Resolution: Sensor resolution is generally defined as the smallest subtended angle at which two separate objects appear to be separate and is dependent on the detection wavelength and sensor quality. However, in an aerial or satellite image mapping context, resolution is usually expressed as the average linear planimetric distance between such objects. The resolution with which a temporal change in position (e.g. of a vegetation boundary) between two images of the same area can be resolved must also include the uncertainty or error in alignment of the images so resolution of change is lower than that of the separate images.

RSC: Remote Sensing Centre at UPNG.

Secondary tropical forest: Forest that is regenerating following cessation of disturbances such as fire, logging or shifting cultivation. Also known as Successional or Seral forest. Regenerating forest may take many centuries (e.g. 200-300 years) to reach an equilibrium age structure and composition resembling primary forest. Initially, regenerating forest is dominated by fast-growing, short-lived shrubs, climbers and trees; later, slow-growing, long-lived shade-tolerant species become dominant. Regenerating stands generally follow thinning curves that represent the gradual replacement of many small trees by a few large trees. Production may be nearly constant but accumulated biomass generally rises at a declining rate until the primary structure is reached when respiration and decay equal production. Initially secondary forest is recognisable from above because of the extensive tree destruction and canopy gaps, however, once an intact canopy has developed it is difficult to recognise by remote sensing with a resolution of only 10-20 m: at this resolution larger disturbance features such as old logging roads provide an indication that adjacent forest has been logged.

SPOT: Système Pour l'Observation de la Terre.

TM: Landsat Thematic Mapper.

TREES: Tropical Ecosystem Environment observation by Satellite project.

UPNG: University of Papua New Guinea.

Wall to wall assessments: The term 'wall to wall' is used to describe a complete national coverage in which all areas are mapped as opposed to studies that only sample part of a country and extrapolate the results to the whole national area.

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"The combination of subsistence farming, intensive forest exploitation, agricultural development, access roading and mining activities, predict that the lowland rainforest as a feature of PNG is a passing one. If we act now we may be able to retain some areas as natural museums" – **White, K.J., Assistant Director, Office of Forests, 1971.**

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