Lowering Emissions in Asia's Forests (LEAF)

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South and Southeast Asia REDD+ Atlas

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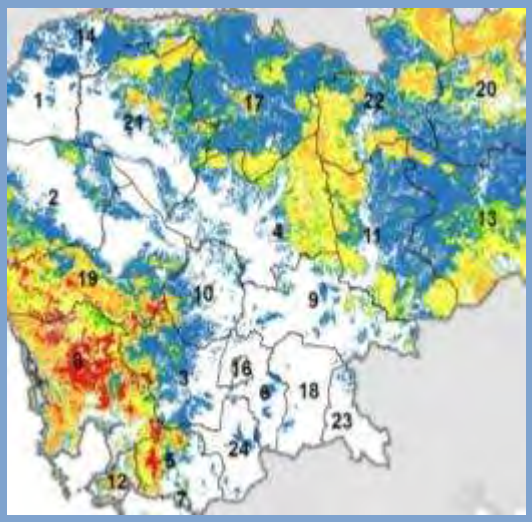
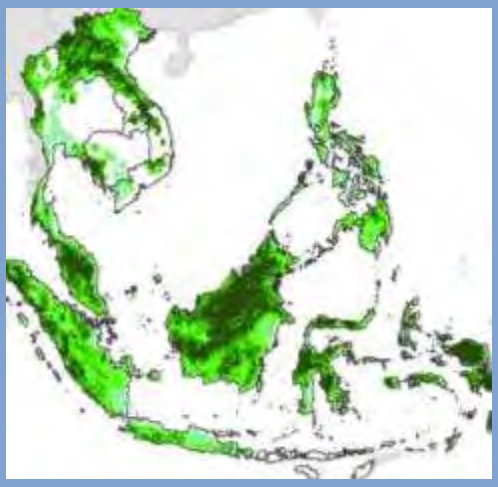
Silvia Petrova, Sandra Brown, Michael Netzer, Brian Bean and Alexandre Grais





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1. ABOUT THIS ATLAS

1.1 PROJECT BACKGROUND

The Lowering Emissions in Asia"s Forests (LEAF) project is an important contributor to increasing global efforts to counter deforestation and forest degradation and associated GHG emissions. LEAF is focused on, six countries in Southeast Asia (Cambodia, Laos, Malaysia, Papua New Guinea, Thailand, Vietnam), and is working to quantify the value of services provided by forests and natural resources and to develop mechanisms for delivering payments for successful management of these services. The main emerging international mechanism is Reduced Emissions from Deforestation and Forest Degradation (REDD+), which seeks to provide financial incentives to support performance-based forest conservation and associated emission reductions, while also incorporating considerations of larger socioeconomic and other "co-benefits" that include biodiversity conservation, improved livelihoods, gender equity and consideration of marginalized populations.

For mechanisms like REDD+ to function, policy-makers and practitioners must be able to develop a reference level of emissions from past changes in the use and management of national forest lands, assess what interventions can be implemented in their future development strategies and how these will affect future emission scenarios, and develop a system to monitor the performance of their interventions on reducing emission from their forest lands. This requires access to quality data that are gathered through rigorous standards and collection methods and processed and managed with thorough quality control processes. To date, there are a variety of available datasets related to forests and emissions of greenhouse gases (GHGs) that have been collected for different purposes and scales, and thus are often difficult to integrate and harmonize. Attempts to integrate these data sets have led to high uncertainties surrounding estimates of forest cover, rates and extent of deforestation and forest degradation and GHG emissions. The data on these topics for the LEAF region are no exception and there is a clear need to develop a common starting point across the region.

1.2 PURPOSE

The purpose of this Atlas is to serve as this starting point to provide a standardized source of information for the larger South and Southeast Asia region by presenting a comprehensive collection of the most relevant, current and trusted datasets available to the public. It includes maps and tables of a range of datasets relevant to REDD+ including forest cover, biomass carbon stocks, and carbon emissions from deforestation. In addition, data are provided for a series of associated land-based biophysical and socioeconomic factors that can be used to understand past patterns of land cover and land use change. The Atlas is meant to serve as a resource to a range of stakeholders who are working with, or interested in, forestry, land use, and climate change in the region. This initial version is "Version 1.0" – its format allows for updates, additions, and other improvements as new data become available. The authors hope that others will use this as an opportunity to share additional data, analyses, or thoughts that may be used to update future versions.

The datasets included in the subsequent chapters cover the region as a whole, and are also presented for each LEAF country (Cambodia, Laos, Malaysia, Papua New Guinea, Thailand, and Vietnam,) in a separate chapter. The datasets can be used as the basis for a wide range of activities, including science-based analysis of threats of deforestation to inform policy-makers and implementers in their design of emission-reduction strategies, or for countries and practitioners to determine historic emissions and define national circumstances to support them as they develop strategically targeted interventions.

2. SOUTH AND SOUTHEAST ASIA

As a regional project, LEAF considers factors related to GHG emissions from the forest and land use sector on a regional basis across a range of countries. For the purpose of framing the topics covered in this chapter in a regional context, the data presented covers the following countries: Bangladesh, Bhutan, Cambodia, India, Indonesia, Laos, Malaysia, Nepal, Papua New Guinea (PNG), Philippines, Thailand, and Vietnam.

2.1 REGIONAL STATISTICS RELATED TO REDD+

2.1.1 Forest Cover

The extent of forest cover is one of the basic statistics that should be known if a country wants to develop a national or sub-national REDD+ program and activities. The distribution of forests in 2000 across the region in terms of percent forest cover per 18.5 km block (forest cover less than 10% is not mapped) is shown in Figure 1[1].

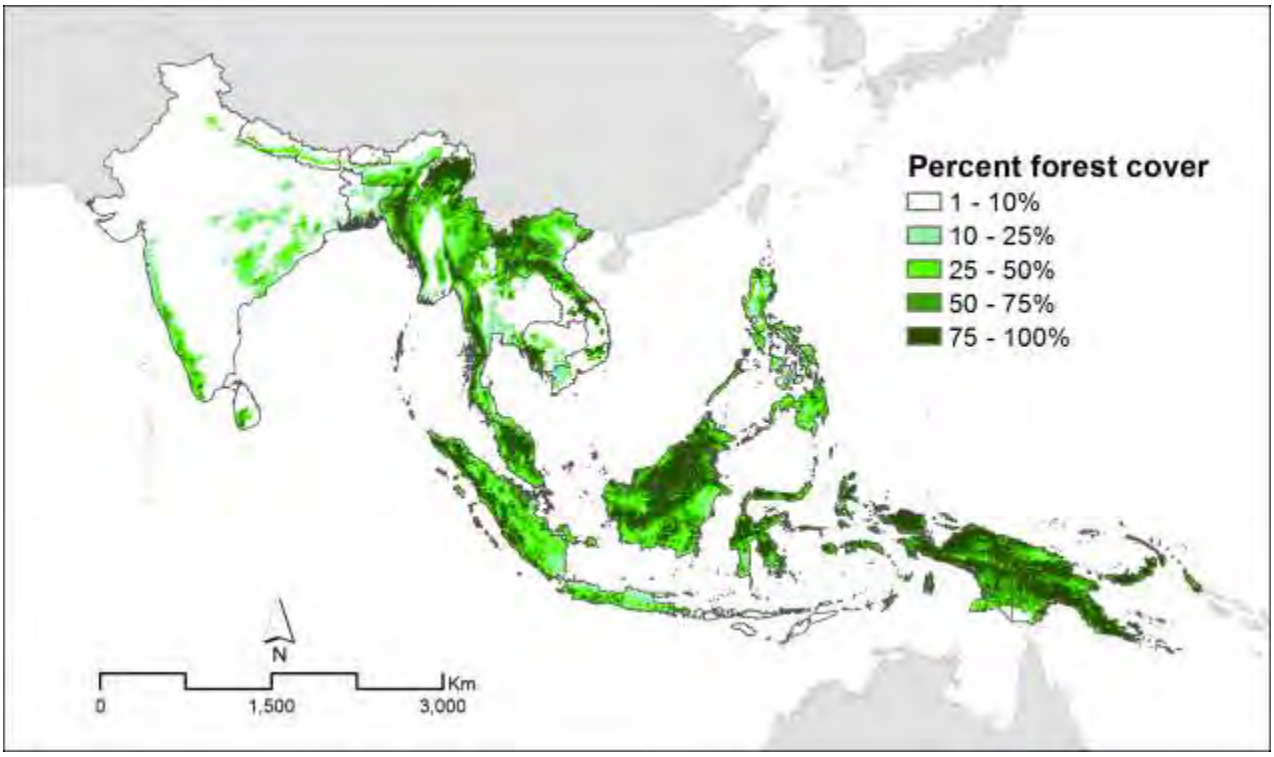


Figure 1. Distribution of Landsat-calibrated forest cover in 2000 across the region, presented as percent forest cover per 18.5km block.

About 37% of the total land area of the region is covered by forests (Table 1). Indonesia alone accounts for more than a third of the region"s total forest cover (about 38%), followed by PNG and India.

[1] There may appear to be certain discrepancies between the extent and estimated area of forest cover between the data presented in the regional and country-specific chapters. This is due to the fact that different forest cover datasets were used for the regional and the country chapters. For this regional chapter, Landsat-calibrated data was used to report the area of forest area per country using sophisticated algorithms that were not applicable for national scale. For subsequent country-specific chapters, a forest cover dataset derived from VCF MODIS 2001 data and presenting forests as area with at least 25% canopy cover was used to display the extent and report the area of forest cover at national scale.

Table 1. Country-level estimates of forests and percent of country area in forest cover in 2000[2].

LEAF Country	Country Area (Million ha)	National Forest Cover (Million ha)	Percent of Country Area in Forest Cover (%)
Bangladesh	14	2	14%
Bhutan	4	2	58%
Cambodia	18	9	51%
India	309	42	13%
Indonesia	191	107	56%
Laos	23	16	69%
Malaysia	33	22	66%
Nepal	15	5	33%
Papua New Guinea	47	38	81%
Philippines	30	10	34%
Thailand	52	17	33%
Vietnam	33	14	41%
Total	**768**	**283**	**37%**

[2] The country-specific forest cover area in this table may differ slightly from the figures cited in the country-specific chapters due to differences in data and methods for calculating forest area at regional and national /subnational scales.

2.1.2 Forest Cover in Protected Areas

Forest cover in protected areas is shown in Figure 2, with a summary of the actual values presented in Table 2.

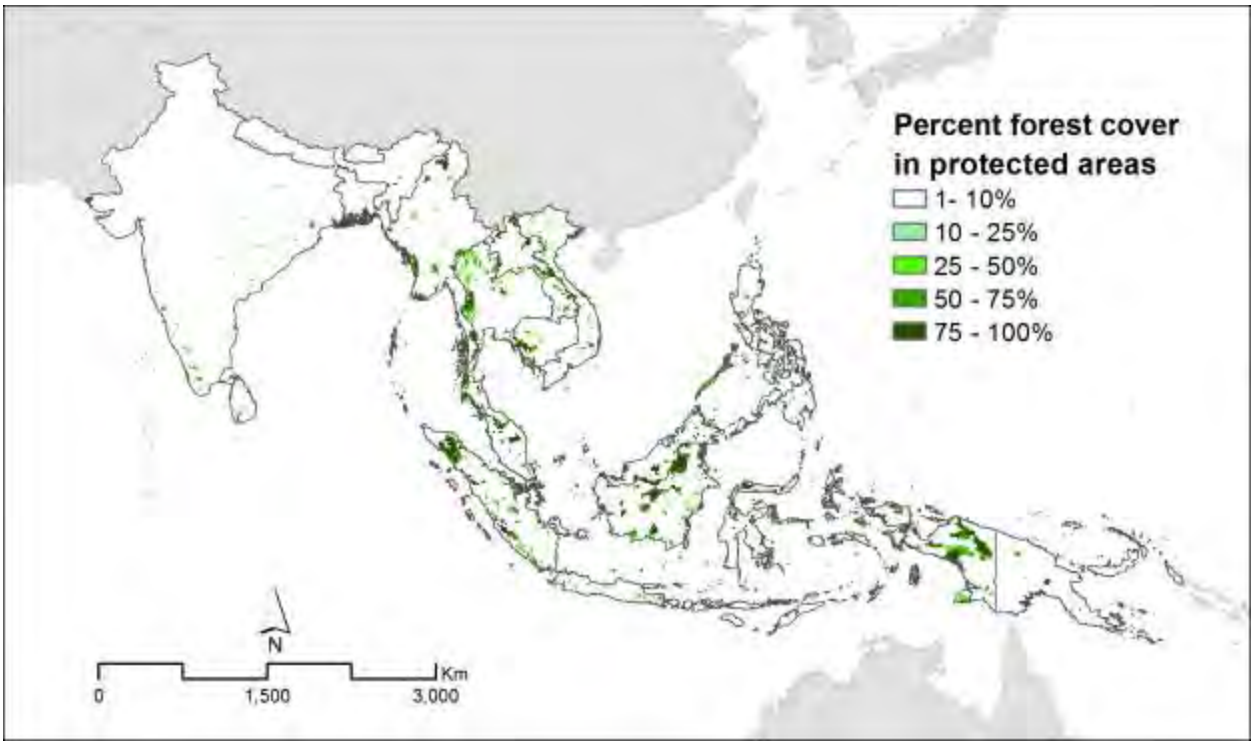


Figure 2. Distribution of Landsat-calibrated forest cover in 2000 presented as percent forest cover per 18.5km block within the protected areas across the region.

About 21% of total forest cover in the LEAF region is currently under protection (Figure 2), with Thailand having 51% of its forest under protection, followed by Cambodia (25%) and Bhutan (34%) (Table 2).

Table 2. Country-level estimates of forests in protected areas and percent protected forest to the total forest area in 2000.

LEAF Country	Forests in Protected Areas (Million ha)	Percent of Total Forests in Protected Areas (%)
Bangladesh	0.2	8%
Bhutan	0.8	34%
Cambodia	3.2	35%
India	4.8	11%
Indonesia	28.2	26%
Laos	4.0	25%
Malaysia	3.0	14%
Nepal	0.8	17%
Papua New Guinea	0.9	2%
Philippines	1.9	18%
Thailand	8.6	51%
Vietnam	2.2	17%
Total	**58.5**	**21%**

2.1.3 Gross Forest Cover Loss 2000-2005

The annual average gross forest cover loss between 2000 and 2005 is shown in Figure 3, with a summary of the actual values presented in Table 3.

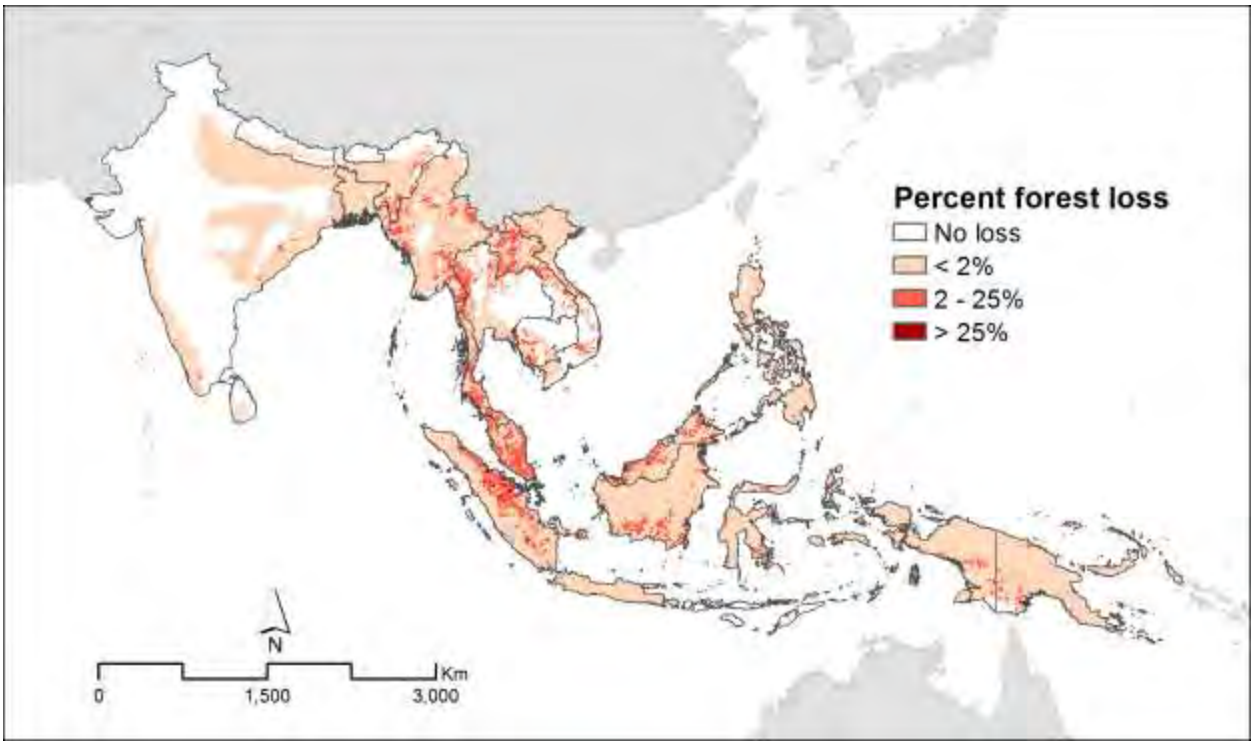


Figure 3. Distribution of percent Landsat-corrected forest cover loss 2000-2005 per 18.5 km block across the region.

Across the LEAF region, the average annual forest loss between 2000 and 2005 was 0.5% of the total forest cover in 2000. Malaysia had the highest percent average annual loss expressed as a percent of forest cover in 2000 (1.1%), while Papua New Guinea had the lowest (0.1%).

Table 3: Country-level estimates of average annual gross forest cover loss between 2000 and 2005 expressed in hectares and as percent of the forest cover in 2000.

LEAF Country	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
Bangladesh	8,163	0.4%
Bhutan	3,858	0.2%
Cambodia	56,532	0.6%
India	205,246	0.5%
Indonesia	690,208	0.7%
Laos	85,965	0.5%
Malaysia	230,988	1.1%
Nepal	16,085	0.3%
Papua New Guinea	48,590	0.1%
Philippines	38,220	0.4%
Thailand	133,608	0.8%
Vietnam	54,364	0.4%
Total	**1,571,826**	**0.5%**

2.1.4 Biomass Carbon Stocks

The distribution of carbon stocks across the LEAF region is shown in Figure 4.The national area weighted carbon stocks as well as the total carbon stocks for the forest area in 2000 are reported in Table 4.

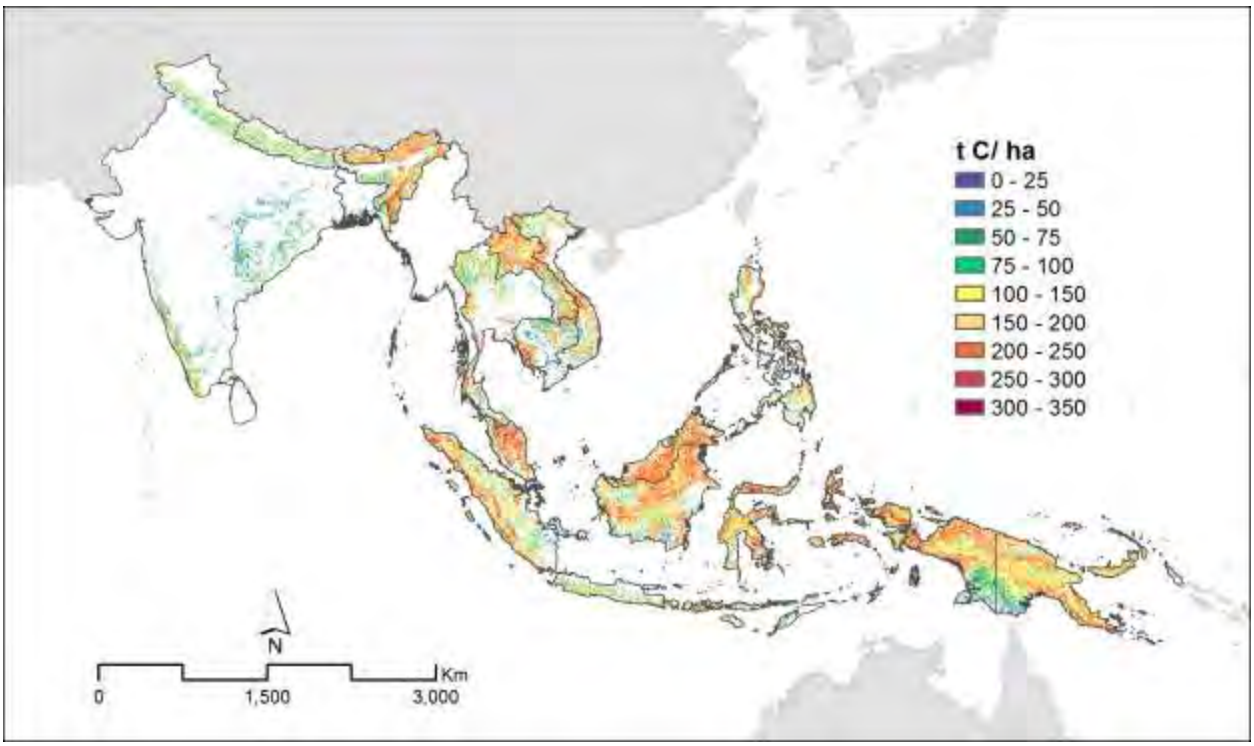


Figure 4. Distribution of above and belowground forest biomass carbon stocks across the region.

The area weighted average carbon stocks across the LEAF region was 133 t C ha^{-1} and the total carbon stocks was 45,360 Million t C. Malaysia is the country with highest area weighted carbon stocks (179 t C ha^{-1}) followed by Laos (164 t C ha^{-1}) and Indonesia (155 t C ha^{-1}), while Bangladesh is the country with lowest area weighted carbon stocks (94 t C ha^{-1}). Indonesia"s forest stored the largest amount of carbon (19,775 Million t C), while Bangladesh"s forest stored the least amount of carbon (115 Million t C).

Table 4. Country-level estimates of above and belowground forest carbon stocks. Forest carbon stocks values are generated for forests with at least 25% tree cover.

LEAF Country	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Million t C)
Bangladesh	94	115
Bhutan	152	576
Cambodia	127	1,150
India	104	4,338
Indonesia	155	19,775
Laos	164	3,016
Malaysia	179	4,502
Nepal	103	694
Papua New Guinea	152	6,122
Philippines	118	1,489
Thailand	126	1,821
Vietnam	127	1,762
Total	**133**	**45,360**

2.1.5 Carbon Emissions from Deforestation

Spatial representation of location and quantity of carbon emissions across the region at 18.5 km block scale is illustrated in Figure 5, with country level estimates of annual CO_2 emissions from deforestation for all LEAF countries given in Table 5.

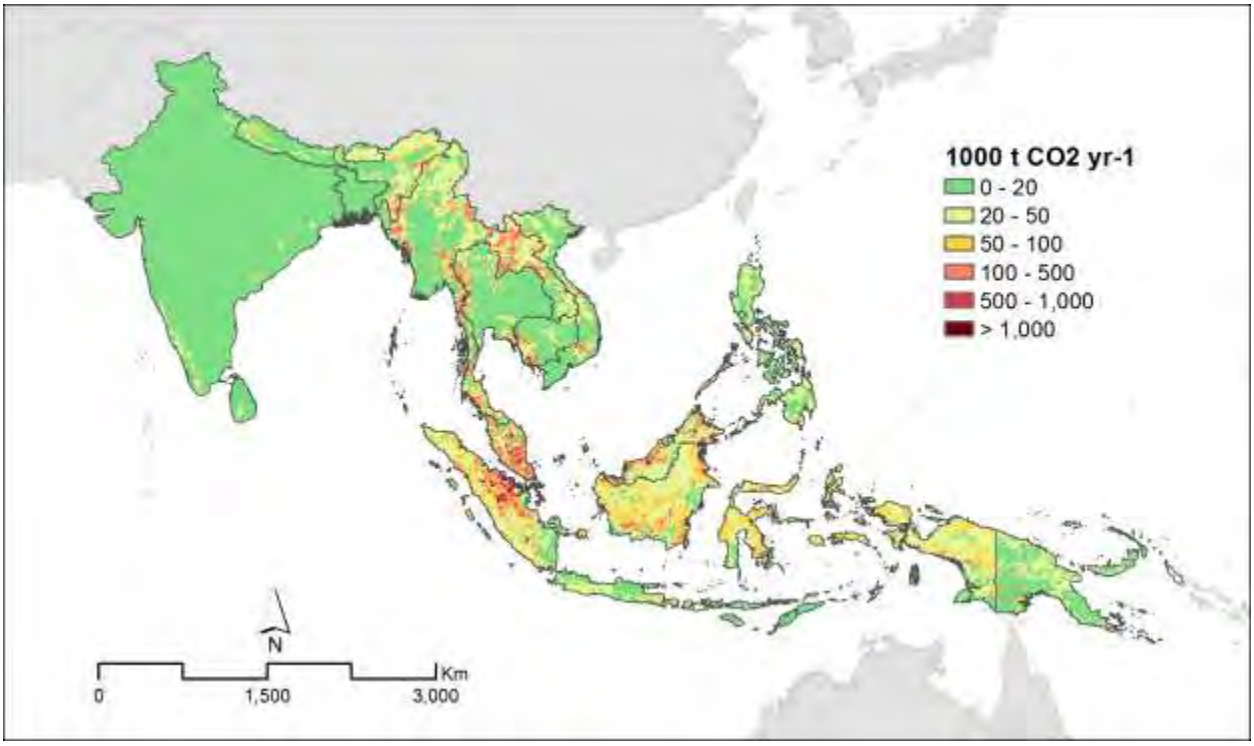


Figure 5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005 for the region.

The total annual CO_2 emissions from deforestation for the region were estimated at 668 million t CO_2 yr^{-1}, with Indonesia and Malaysia being the largest emitters.

Table 5. Country-level estimates of carbon emissions from deforestation from 2000-2005.

LEAF Country	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
Bangladesh	1,657
Bhutan	2,577
Cambodia	20,700
India	47,102
Indonesia	319,925
Laos	47,128
Malaysia	120,206
Nepal	6,809
Papua New Guinea	25,294
Philippines	15,089
Thailand	38,132
Vietnam	23,587
Total	**668,205**

2.2 FACTORS FOR REGIONAL CIRCUMSTANCES

This section presents some of the most common spatially explicit factors that are used to explain patterns of deforestation and pressure on the forests in the LEAF countries. Maps of roads, settlements, climate, rural population growth and protected areas are shown in Figure 6 - 12.

2.2.1 Elevation

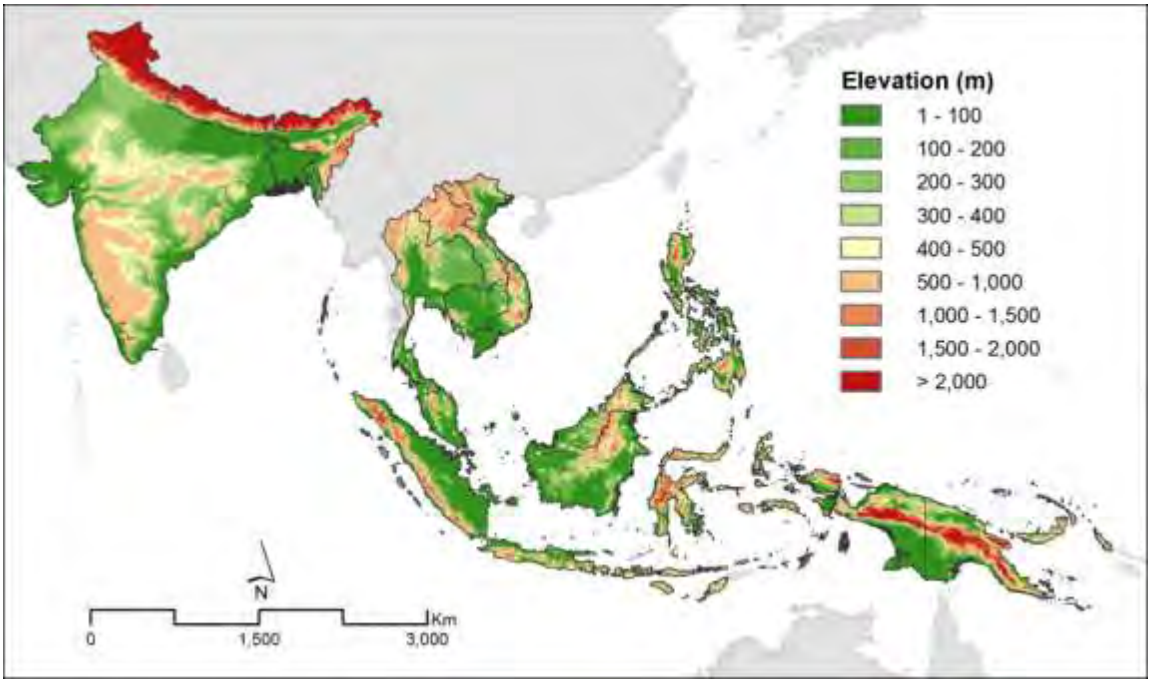


Figure 6. Elevation across the region.

2.2.2 Roads

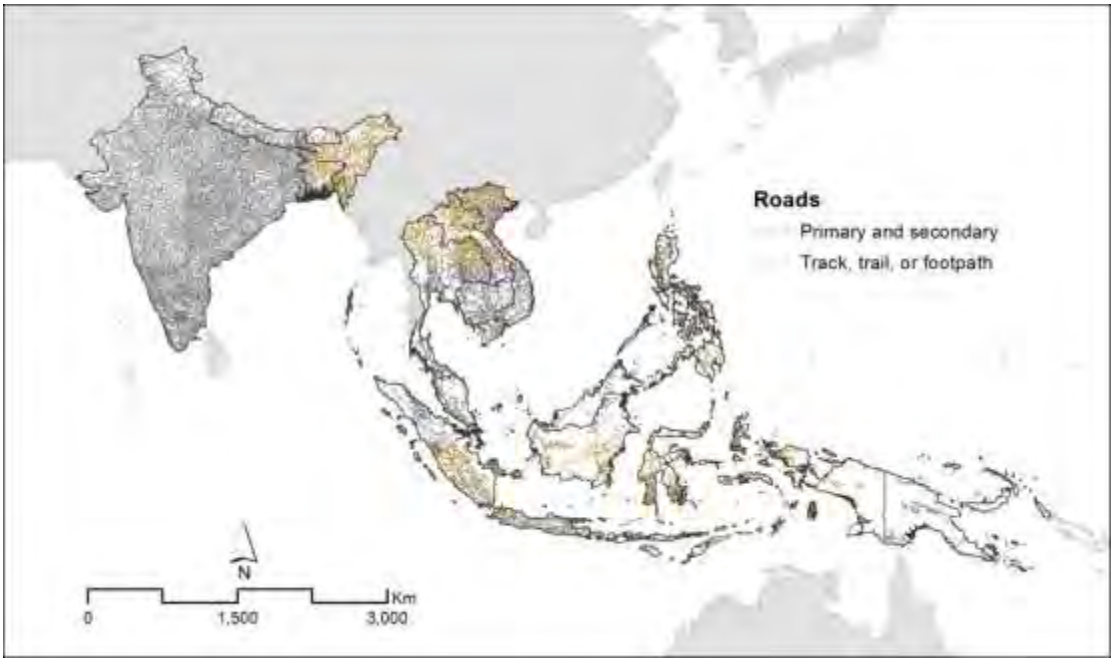


Figure 7. Location and type of roads across the LEAF region.

2.2.3 Settlements

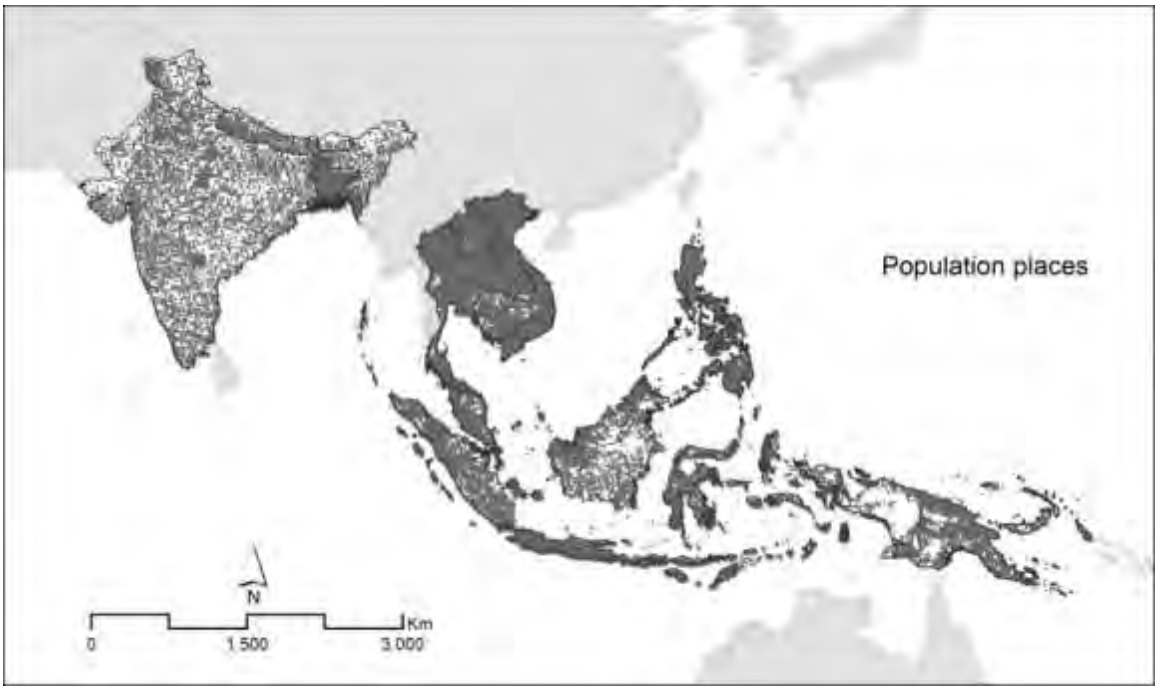


Figure 8. Map of all settlements (populated places) in the LEAF region.

2.2.4 Climate

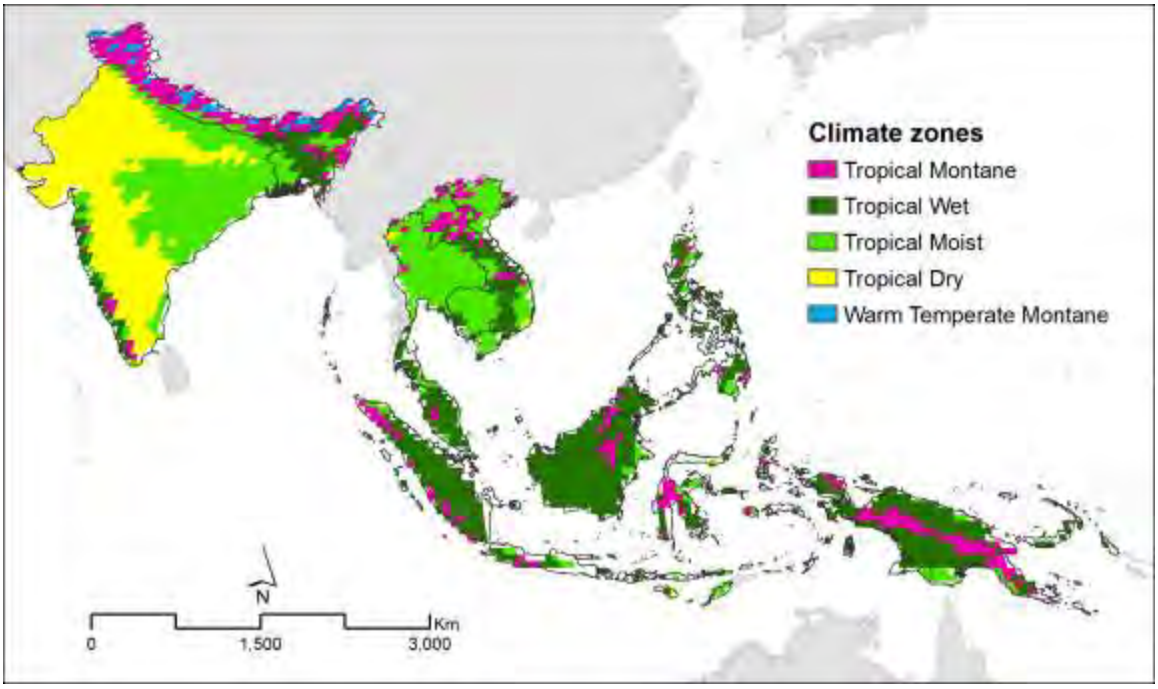


Figure 9. Map of climate zones across the LEAF region.

2.2.5 Soil nutrient availability

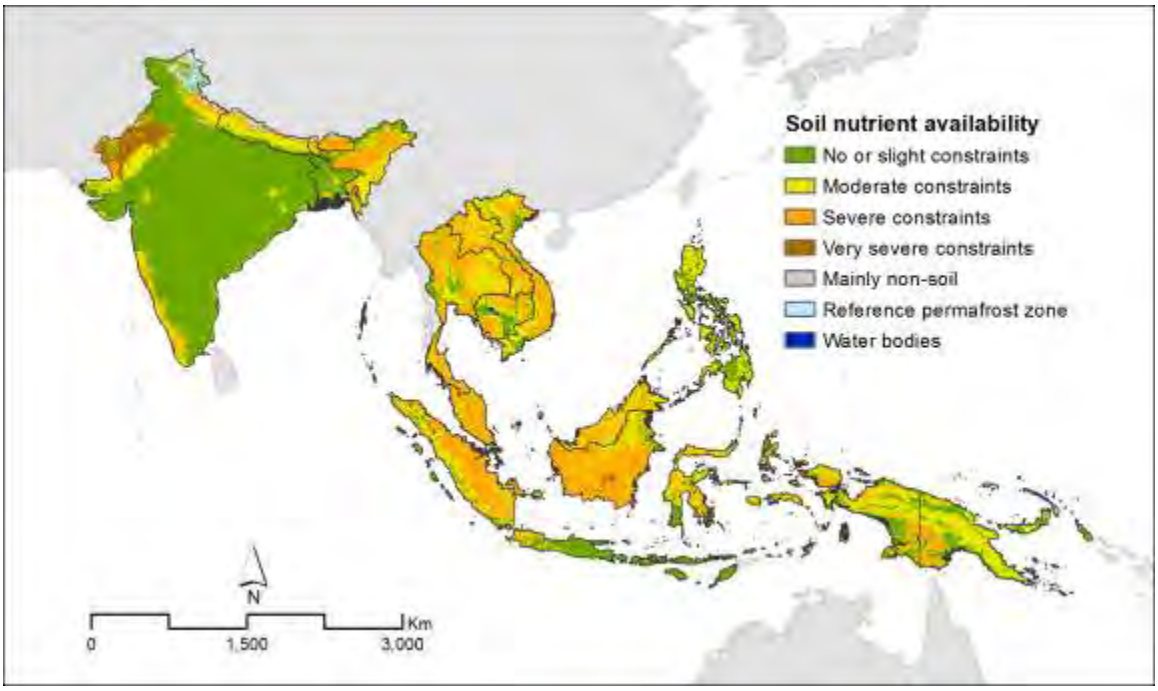


Figure 10. Map of areas with soil nutrient availability across the LEAF region.

2.2.6 Rural Population Growth

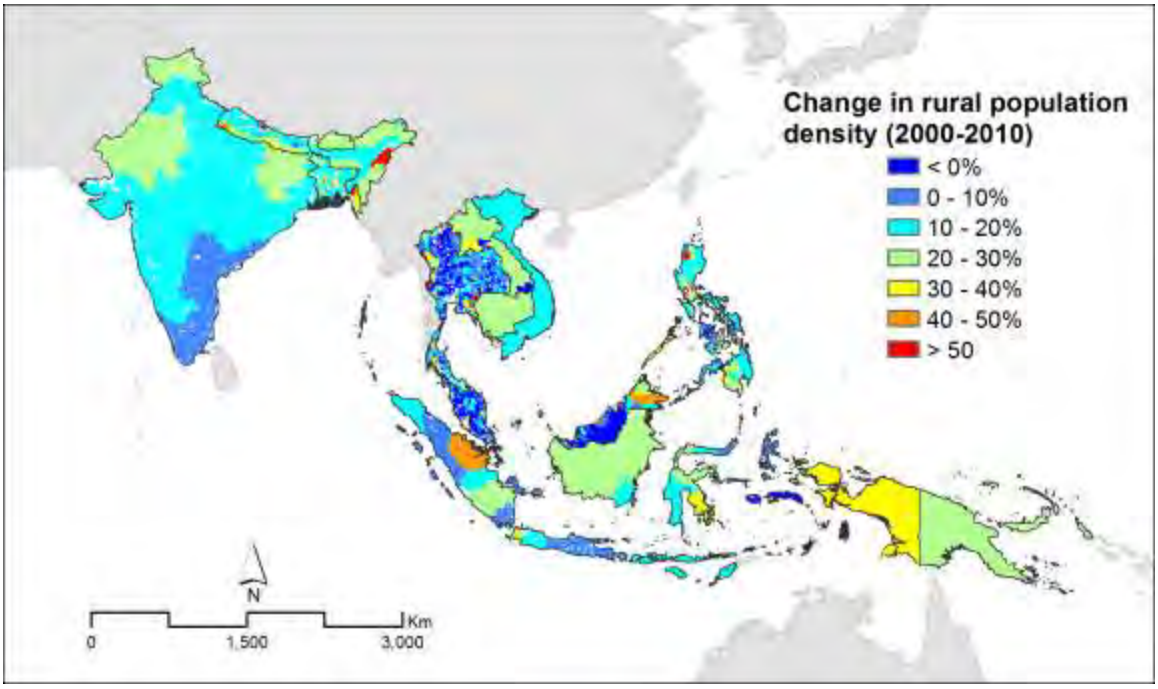
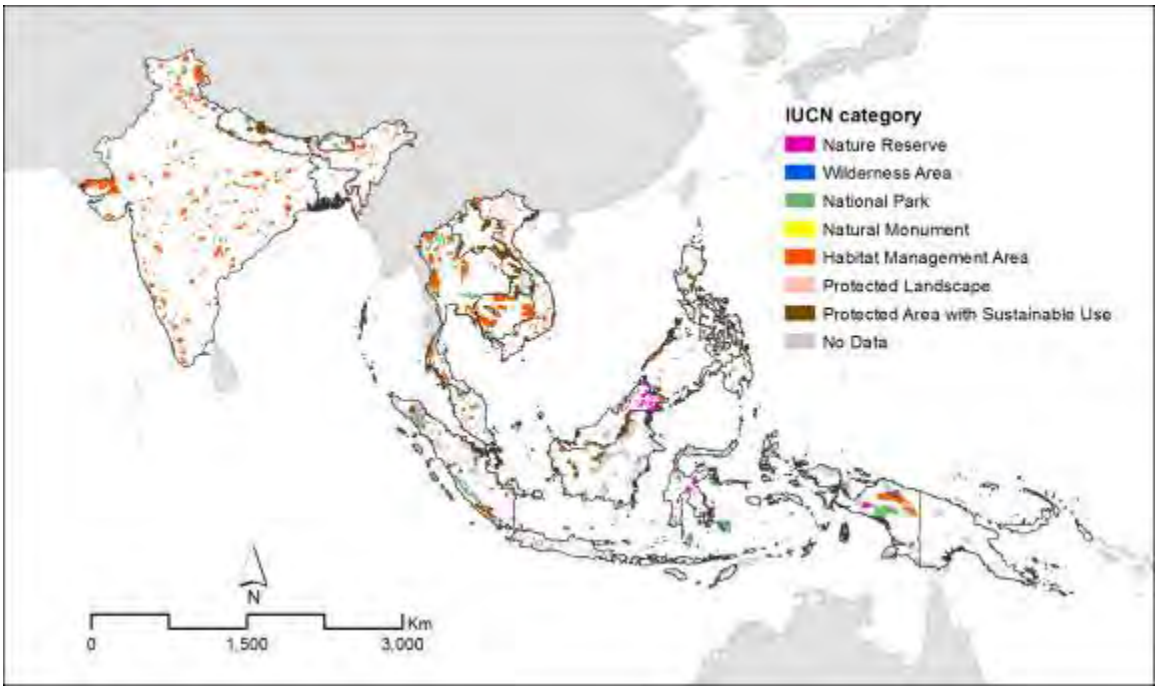


Figure 11. Rural population growth is shown as percent population density change.

2.2.7 Protected areas



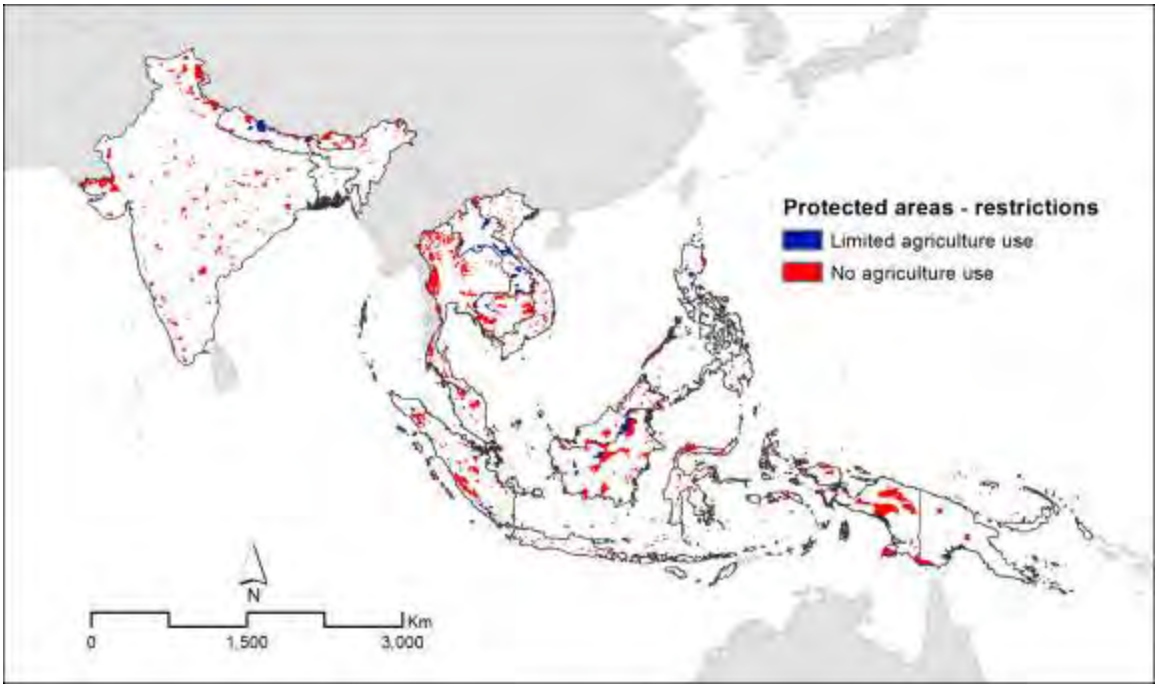


Figure 12. Maps of protected areas by IUCN category (top) and area of protected areas with restrictions on agricultural use (bottom).

2.3 FOREST THREATS

The data presented in the previous sections can serve as the basis for basic analysis to identify areas of concern and potential threat to forests. To examine possible threats to forests in terms of potential for future deforestation, this section presents example spatial overlays of different factors with forest cover. These examples provide just one starting point - planners and implementers can select particular topics of interest to overlay and compare for their local context. For these illustrative purposes, forest cover was defined at 25% tree canopy cover at 1 km spatial resolution.

2.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forests to other land uses depends on the amount of carbon stored in the forest. Understanding where forests with high carbon stocks, and thus the potential for high emissions from deforestation, are located within a country can provide input to development decisions regarding land use planning. For example, if a country has plans to develop a road across forests with high carbon stocks, most likely this road will bring people, who will deforest areas for their agriculture needs, consequently leading to large greenhouse gas emissions from deforestation. Alternatively, if the country knows where the forests with high carbon are located, they potentially could change the road construction plans to avoid these forests or enforce protection around the constructed road. These alternative activities would result in low CO_2 emissions from road construction.

Table 6 reports the percent forest per carbon stock category for each LEAF country. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150-200 t C ha^{-1}), HIGH 200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}). Figure 13 illustrates the location of the forest carbon categories across the LEAF region. The majority of forests in the region were classified in the MEDIUM HIGH carbon category (35%), and the least area of the forest was classified in VERY HIGH carbon category (2%).

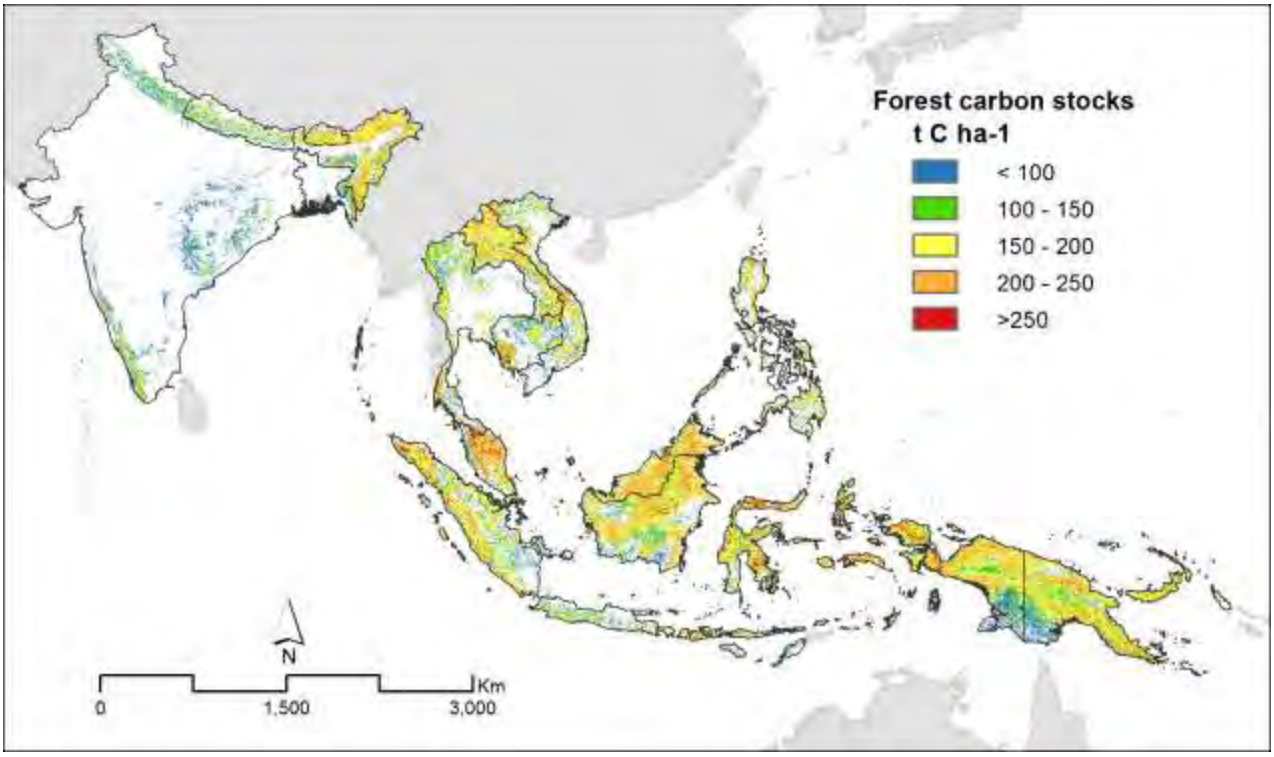


Figure 13: Forest carbon stocks for forest cover in 2000 across the LEAF region.

Table 6: National estimates of percent forest cover per carbon stock category. Carbon stock categories are defined as LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}).

LEAF country	Forest cover (Million ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
Bangladesh	2	1	12	11	26	51
Bhutan	2	2	27	53	9	9
Cambodia	9	3	16	33	11	37
India	42	1	15	23	16	46
Indonesia	107	4	23	38	18	18
Laos	16	1	28	50	10	11
Malaysia	22	8	38	35	10	10
Nepal	5	0	7	37	20	35
Papua New Guinea	38	1	20	41	22	15
Philippines	10	1	21	28	24	27
Thailand	17	1	17	34	17	30
Vietnam	14	1	23	34	17	25
Total	**283**	**2**	**21**	**35**	**17**	**26**

2.3.2 Analysis #2: Forest and agriculture suitability

A major driver of deforestation is conversion to agriculture (small or large scale). Close examination of factors such as soil nutrient availability can allow planners and policy makers to make informed predictions of areas that may be under significant future threat. The overlays represented in the map in Figure 14 identify forest areas located on soil with no or slight to moderate constraints of nutrient availability. These areas would be deemed as suitable for agriculture, while forest located on soil with high and very high constraints of nutrient availability would be expected to be less suitable for agriculture, and therefore less likely under threat. The red color indicates forest area under threat, and the green represents low threat.

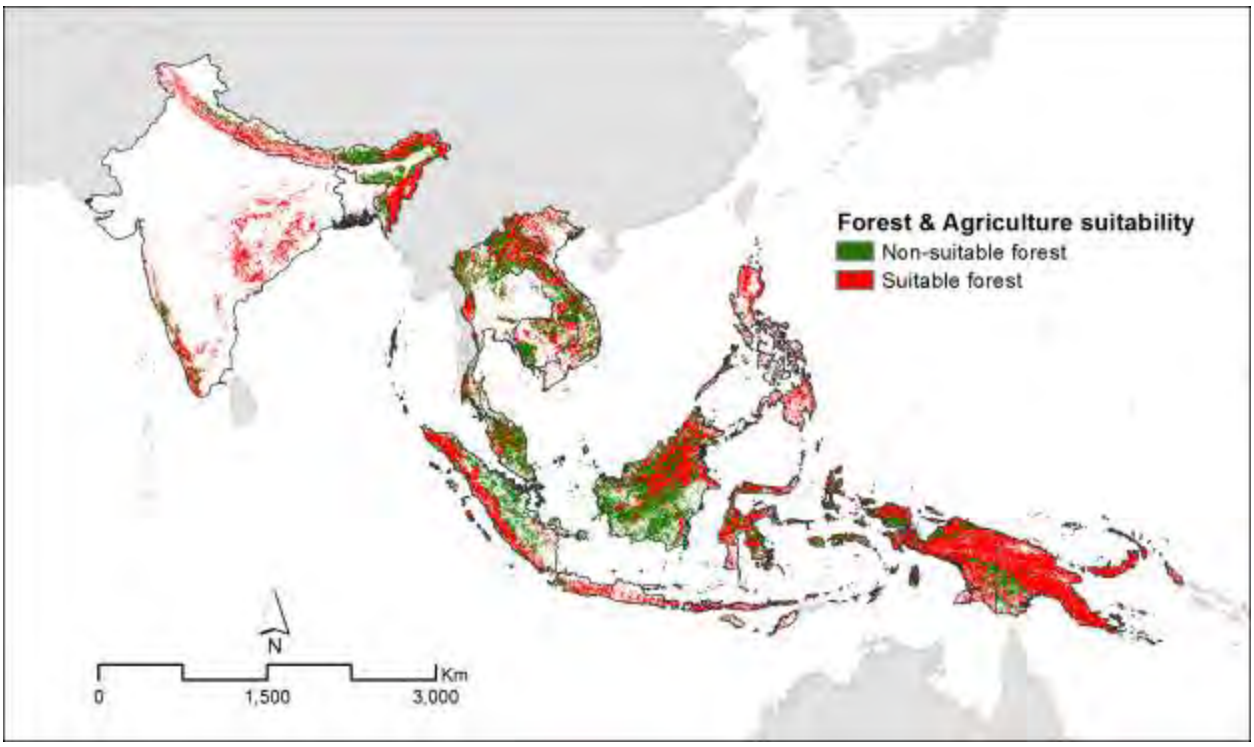


Figure 14. Spatial overlay of forest areas in 2000 with no or slight to moderate constraint (red) and with high and very high (green) constraints on soil nutrient availability.

2.3.3 Analysis #3: Forest and road network

Road networks provide access to forest areas, thus deforestation and forest degradation is more likely to occur in forests close to roads than in forests far away from roads. To examine accessibility to forest areas, we created a buffer of five kilometers (km) around all roads in the LEAF region and assumed that forests located within this buffer to be more accessible than the forests outside the five km buffer zone. Figure 15 illustrates the accessible forest (within this 5 km buffer zone) and the less accessible forest (outside the 5 km buffer zone). As with the previous map, red indicates forests under threat, and green represents forests under less threat.

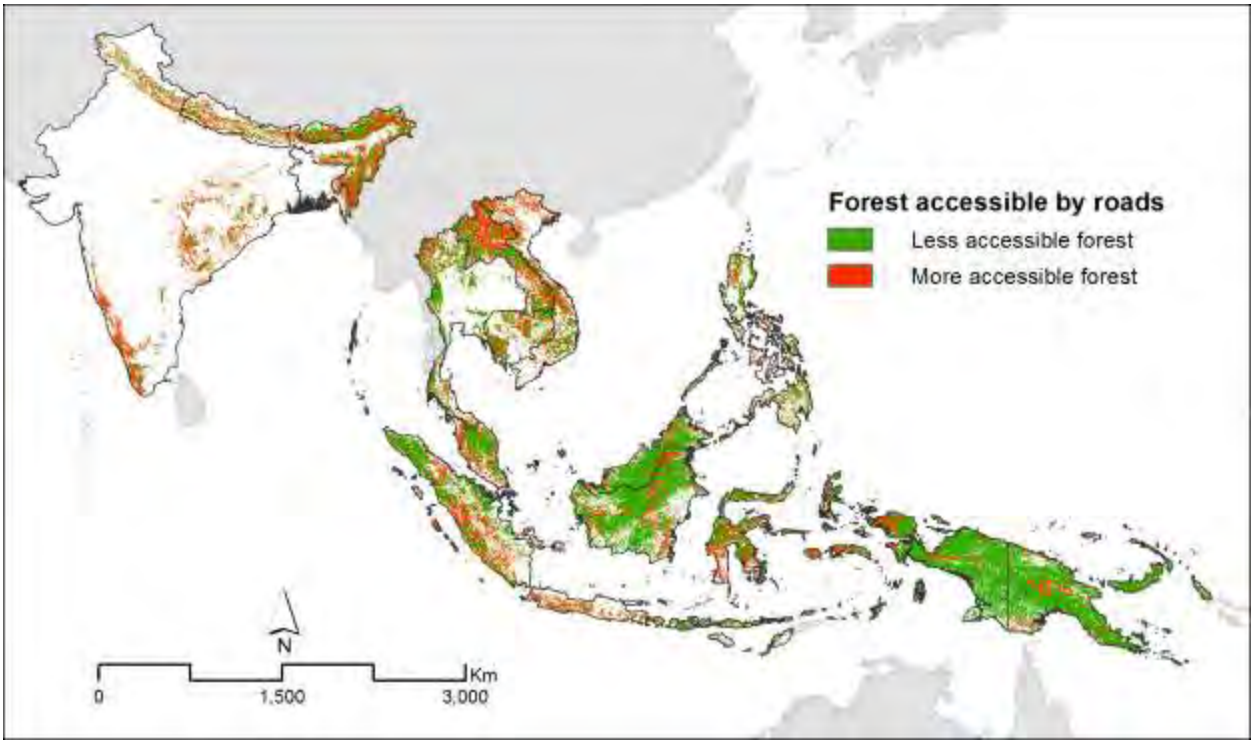


Figure 15. Spatial overlay of forest cover and 5km buffer zone around primary and secondary road network. More accessible forests are defined as forests within 5 km buffer zone and less accessible forest are defined as forests outside this buffer.

2.3.4 Analysis #4: Forest and change in population density

Increase of population results in demand for increased area for agriculture use. The map in Figure 16 illustrates the spatial overlay of forest cover and change in rural population density between 2000 and 2010 across the LEAF region. Areas colored in dark blues define forests where the rural population density decreased, while areas colored in orange and red define forests where the rural population density increased by more than 40% between 2000 and 2010.

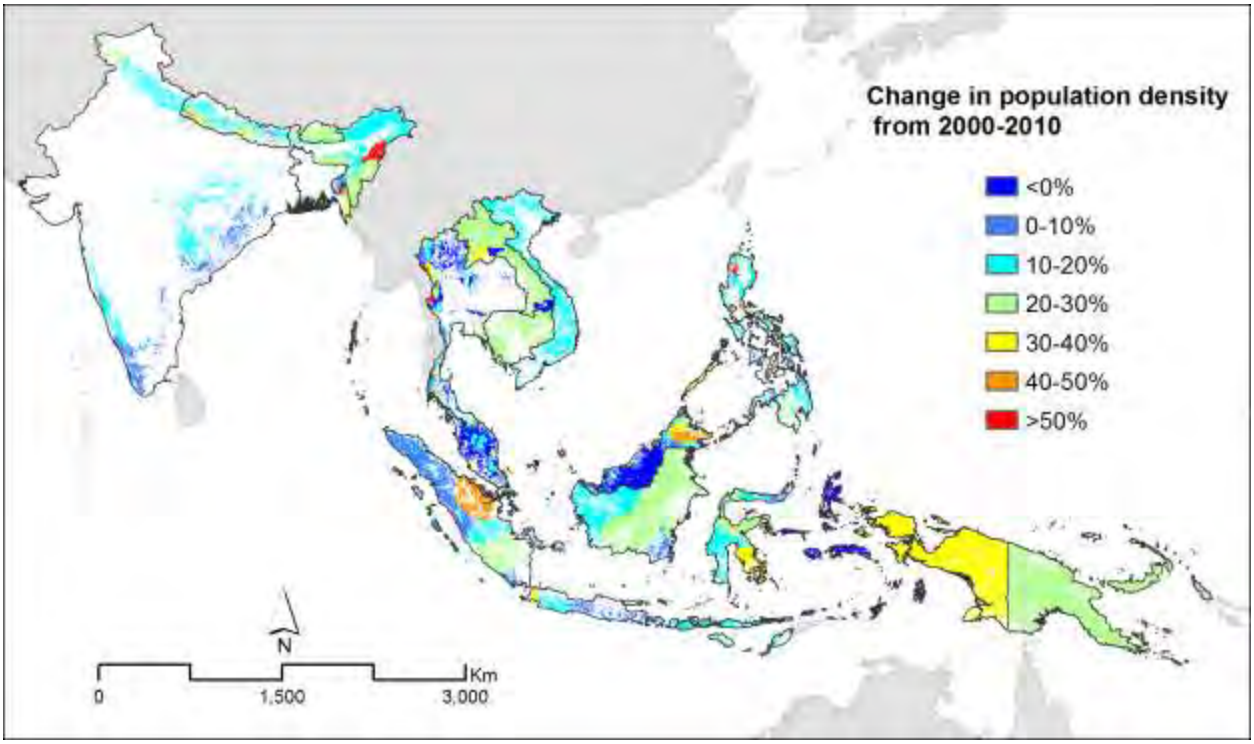


Figure 16. Spatial overlay of forest cover and change in rural population density between 2000 and 2010.

2.3.5 Analysis #5: Forest and elevation

Forests at low elevation tend to be under high threat of deforestation simply because more people live at low elevation. Elevation across LEAF region ranges from 1 to 8,848 m and was classified into three categories: low (1-500m), medium (500-1500m) and high (>1500) elevation. The preponderance of the color red shows that most of the forests in the region are located below 500 m elevation, and can be expected to be under higher threat (Figure 17).

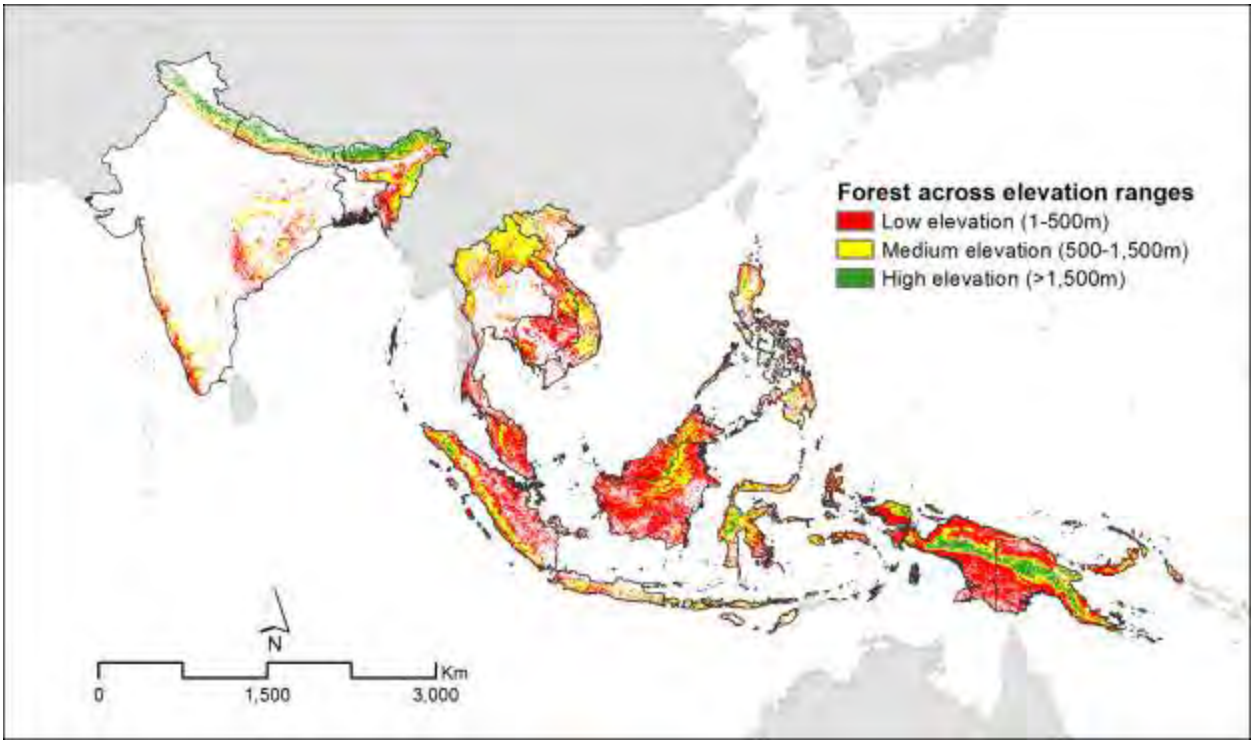


Figure 17: Forest cover in 2000 according to elevation categories.

3. CAMBODIA

This section presents the same maps and statistics given in the South and Southeast Asia Atlas (Chapter 2) reported at the subnational level for Cambodia. These highlight key factors that should be considered for defining national circumstances, and illustrate forest threats based on roads, change in population density, elevation and suitability for agriculture based on nutrient availability.

3.1 NATIONAL STATISTICS RELATED TO REDD+

3.1.1 Forest cover

A country-specific forest cover map was extracted from a land cover dataset for 2002 provided by World Conservation Society (WCS) to Winrock under a separate project. The land cover dataset was developed by the Ministry of Forestry, Cambodia and WCS and presents a better understanding of the extent of the forest cover in Cambodia than the global MODIS datasets. Total forest area for Cambodia based on these data (Table C-1) differs from the forest area reported under the Regional Atlas Section 3.1 Table 1.

Figure C-1 shows the extent of forest cover in 2002 across the provinces in Cambodia and Table 1 reports the forest coverage per province and percent of the province area covered by forest. According to spatial data, the Prey Veaeng province has the least forest cover (2%), while Preah Vih province has the largest extent of forest (92 %).

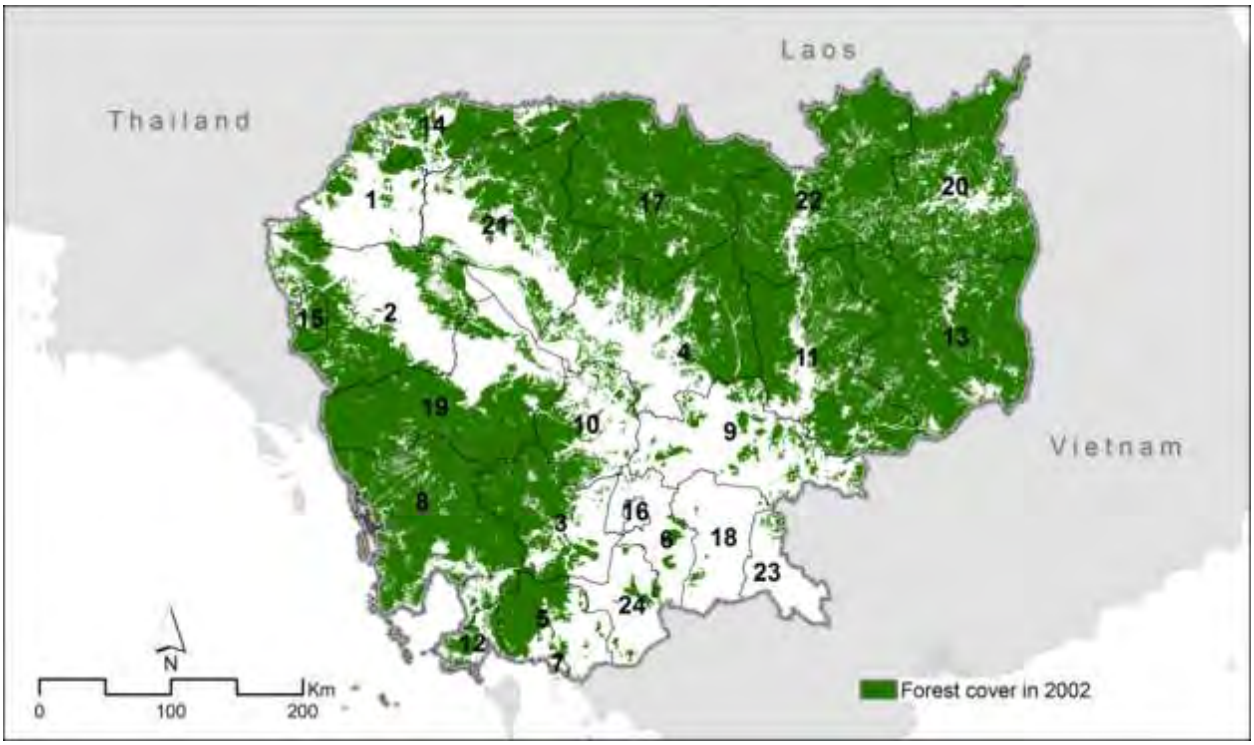


Figure C-1. Forest cover in 2002 across Cambodia. Forest cover is extracted from a land cover map provided by the WCS. Provinces are labeled according to 'Map ID' information provided in Table C-1.

Table C-1. Province level estimates of forests and percent of province area in forest cover for 2002.

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
1	Banteay Mean Cheay	618	151	24%
2	Battambang	1,215	565	47%
3	Kampong Speu	684	403	59%
4	Kampong Thom	1,287	623	48%
5	Kampot	474	232	49%
6	Kandaal	358	31	9%
7	Kep	15	3	18%
8	Koh Kong	1,234	959	78%
9	Kompong Cham	951	173	18%
10	Kompong Chnang	543	209	38%
11	Kratie	1,201	922	77%
12	Krong Preah Sihanouk	141	72	51%
13	Mondul Kiri	1,370	1,193	87%
14	Otdar Mean Chey	524	353	67%
15	Pailin	109	86	78%
16	Phnom Penh*	37	-	-
17	Preah Vih	1,409	1,291	92%
18	Prey Veaeng	478	9	2%
19	Pursat	1,249	865	69%
20	Ratana Kiri	1,176	928	79%
21	Siem Reap	1,294	634	49%
22	Stung Treng	1,203	1,026	85%
23	Svaay Rieng	287	12	4%
24	Takeo	350	29	8%
	Cambodia	**18,205**	**10,769**	**59%**

** No forest cover and percent forest cover for this province*

3.1.2 Forest Cover in Protected Areas

Figure C-2 illustrates the forest area in protected areas and Table C-2 reports the actual forest area and percent forest in protected area per province.

Figure C-2. Distribution of forest cover in 2002 within protected area across Cambodia. Provinces are labeled according to 'Map ID' information provided in Table C-2.

The province with the highest percent forest in protected area is Mondul Kiri (58%), with 686,000 ha of protected forest. The province with at least percent forest in protected area is Kratie (6%), with 53,000 ha of protected forest

Table C-2. Province level estimates of forests in protected areas and percent protected forests of the total forest area in 2002

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
1	Banteay Mean Cheay	50	33%
2	Battambang	231	41%
3	Kampong Speu	155	38%
4	Kampong Thom	95	15%
5	Kampot	118	51%
6	Kandaal*	-	-
7	Kep	1	40%
8	Koh Kong	410	43%
9	Kompong Cham*	-	-
10	Kompong Chnang	37	18%
11	Kratie	53	6%
12	Krong Preah Sihanouk	24	34%
13	Mondul Kiri	686	58%
14	Otdar Mean Chey	70	20%
15	Pailin	36	42%
16	Phnom Penh*	-	-
17	Preah Vih	515	40%
18	Prey Veaeng*	-	-
19	Pursat	479	55%
20	Ratana Kiri	385	42%
21	Siem Reap	214	34%
22	Stung Treng	98	10%
23	Svaay Rieng*	-	-
24	Takeo*	-	-
	Cambodia	**3,660**	**34%**

** No forest cover and percent forest cover in protected areas for these provinces*

3.1.3 Gross Forest Cover Loss

Forest cover loss for Cambodia was estimated based on the country-specific land cover datasets for 2002 and 2006, both provided by WCS. Figure C-3 illustrates the area of gross forest loss across provinces in Cambodia, and Table C-3 reports average annual gross forest cover loss in hectares and as a percent of forest cover in 2002.

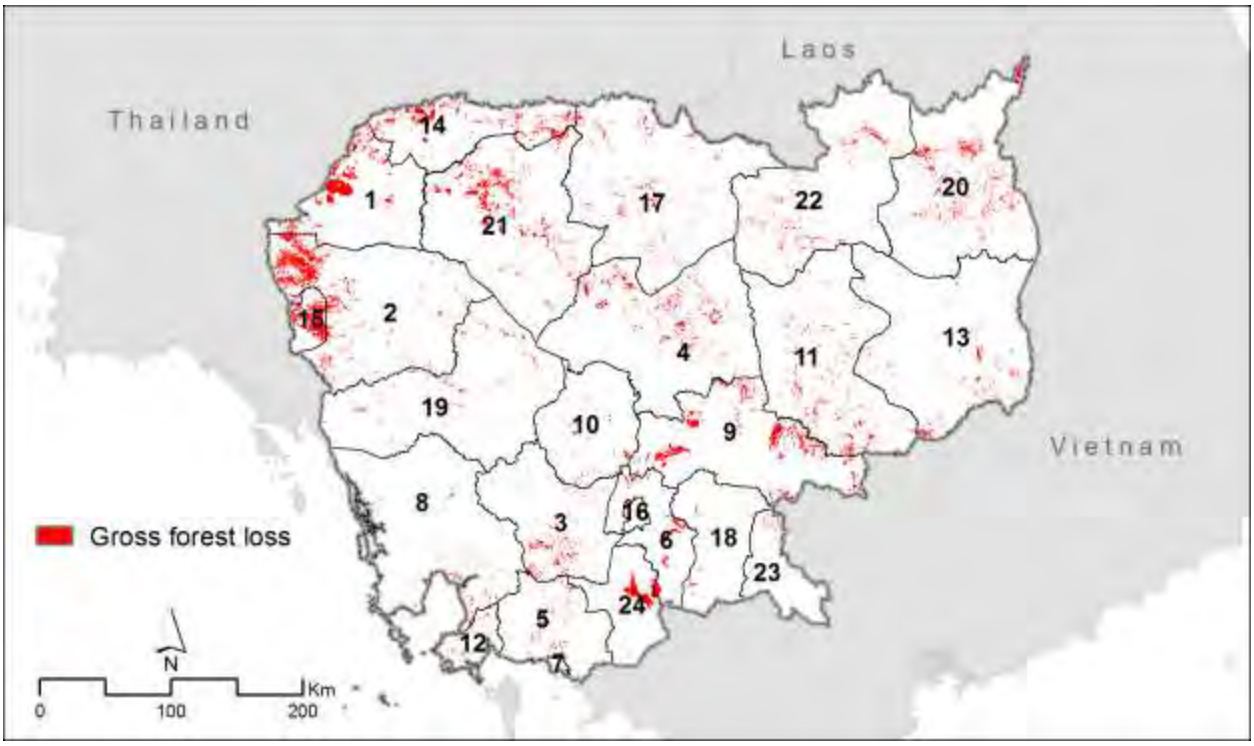


Figure C-3. Distribution of gross forest cover loss between 2002 and 2006 across Cambodia. Provinces are labeled according to 'Map ID' information provided in Table C-3.

Pailin province had the highest gross forest loss (4.4%) expressed as a percent of the initial forest cover in 2002. Preah Vih, Stung Threng, Mondul Kiri, Kratie, Ratana Kiri and Otdar Mean Chey, province had the lowest gross forest loss expressed as a percent of the initial forest cover in 2002, accounted for only 0.1 %.

Table C-3. Province level estimates of average annual gross forest cover loss between 2002 and 2006 expressed as hectares and percent of the forest cover in 2002

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2002 (%)
1	Banteay Mean Cheay	1,767	1.2%
2	Battambang	15,702	2.8%
3	Kampong Speu	2,675	0.7%
4	Kampong Thom	1,257	0.2%
5	Kampot	3,987	1.7%
6	Kandaal	1,058	3.4%
7	Kep*	-	-
8	Koh Kong	4,196	0.4%
9	Kompong Cham	3,781	2.2%
10	Kompong Chnang	594	0.3%
11	Kratie	1,200	0.1%
12	Krong Preah Sihanouk	2,302	3.2%
13	Mondul Kiri	1,459	0.1%
14	Otdar Mean Chey	530	0.1%
15	Pailin	3,803	4.4%
16	Phnom Penh	35	-
17	Preah Vih	1,412	0.1%
18	Prey Veaeng	345	3.7%
19	Pursat	6,058	0.7%
20	Ratana Kiri	1,236	0.1%
21	Siem Reap	1,453	0.2%
22	Stung Treng	1,165	0.1%
23	Svaay Rieng	317	2.7%
24	Takeo	200	0.7%
	Cambodia	**56,532**	**0.5%**

** No gross forest cover loss for these provinces*

3.1.4 Biomass Carbon Stocks

Figure C-4 illustrates the distribution of biomass carbon stocks across forests in Cambodia.

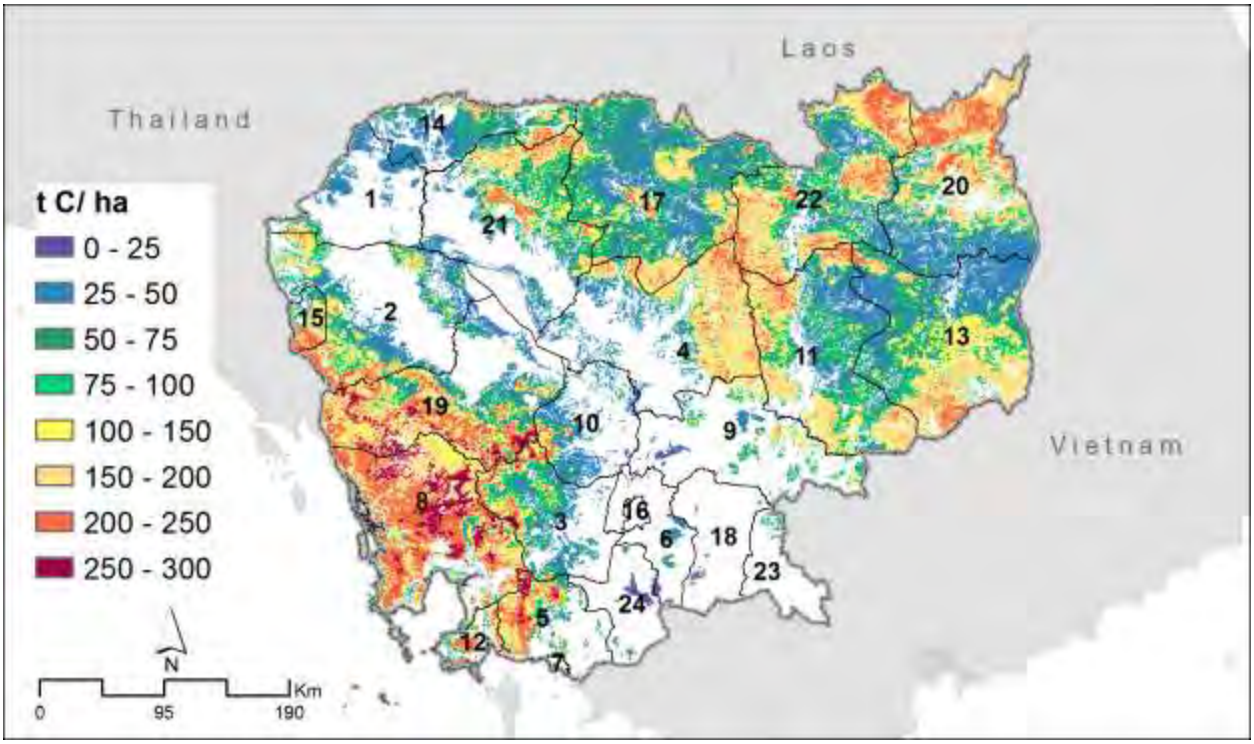


Figure C-4. Distribution of above and belowground forest biomass carbon stocks across Cambodia. Provinces are labeled according to 'Map ID' information provided in Table C-4.

The forests in Koh Kong province were with highest area weighted carbon stocks (192 t C ha^{-1}), while forests in Prey Veaeng province were with the lowest area weighted carbon stocks (28 t C ha^{-1}). The total forest carbon stock for the forest in 2002 was estimated at 1,277 Million t C, with Koh Kong and Stung Treng province contributing the most with 184 and 134 Million t C, respectfully. Kep and Prey Veaeng province contributing to the total forest carbon stocks with less than 1 Million t C.

Table C-4. Province level estimates of above and belowground forest biomass carbon stocks expressed as area weighted average (t C ha^{-1}) and total carbon (t C)

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Million t C)
1	Banteay Mean Cheay	51	8
2	Battambang	101	57
3	Kampong Speu	104	42
4	Kampong Thom	134	83
5	Kampot	158	37
6	Kandaal	40	1
7	Kep*	70	0
8	Koh Kong	192	184
9	Kompong Cham	89	15
10	Kompong Chnang	66	14
11	Kratie	110	101
12	Krong Preah Sihanouk	139	10
13	Mondul Kiri	102	122
14	Otdar Mean Chey	86	30
15	Pailin	151	13
16	Phnom Penh**	-	-
17	Preah Vih	85	109
18	Prey Veaeng*	28	0
19	Pursat	154	133
20	Ratana Kiri	124	115
21	Siem Reap	103	65
22	Stung Treng	131	134
23	Svaay Rieng	61	1
24	Takeo	33	1
	Cambodia	**100**	**1,277**

** Values of zero indicate less than a million t C stocks per province*

*** Cells with no values indicate provinces with no forest cover*

3.1.5 Carbon emissions from deforestation

Annual carbon emissions from deforestation between 2000 and 2005 for Cambodia are shown in Figure C-5. Table C-5 reports the annual emissions from deforestation per province.

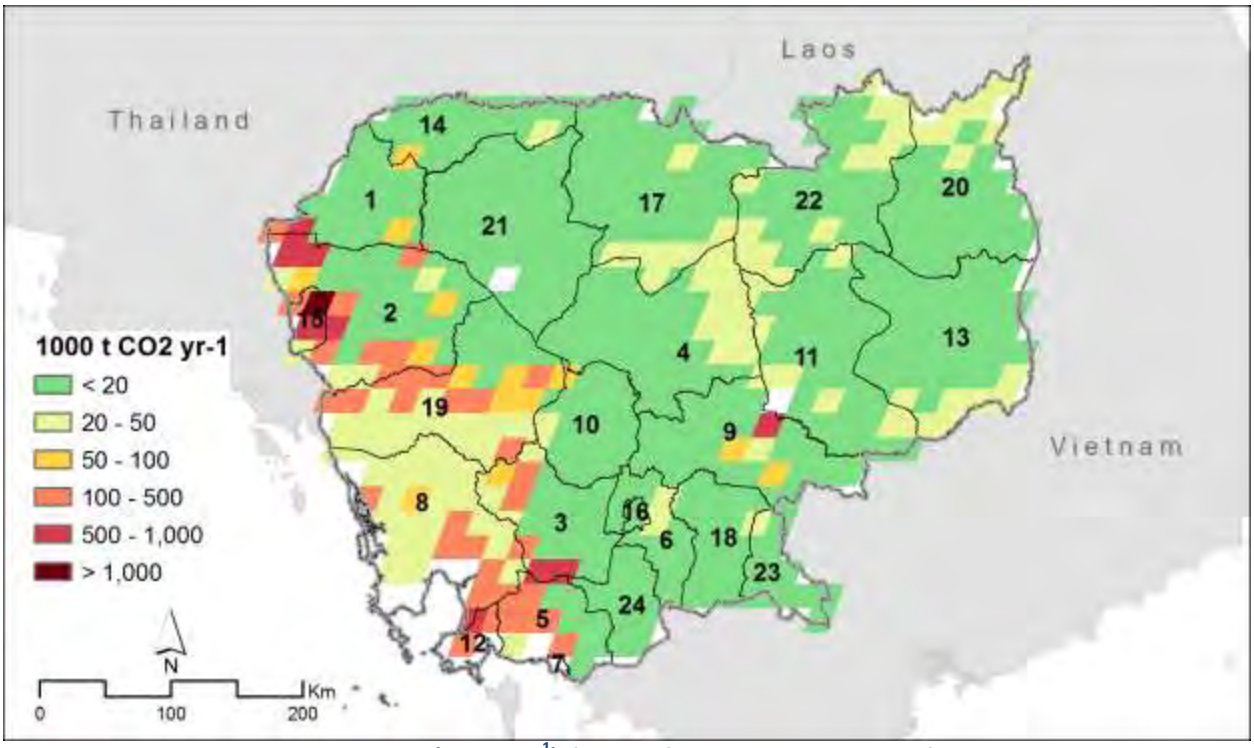


Figure C-5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005 for Cambodia. Provinces are labeled according to 'Map ID' information provided in Table 5.

Battambang province was found to have the highest annual CO_2 emissions from deforestation (4,429,000 t CO_2 yr^{-1}), while Takeo and Phnom Penh province were found to have lowest CO_2 emissions from deforestation (26,000 and 4,000 t CO_2 yr^{-1}, respectively), It should be noted that the national forest cover data do not indicate presence of forest cover in Phnom Penh province, but the national carbon emissions data reported some emissions due to deforestation for Phnom Penh province.

Table C-5. Province level estimates of carbon emissions (t CO2 yr^{-1}) from deforestation between 2000 and 2005.

Map ID	Province	Annual Emissions from Deforestation ($1000\ t\ CO_2\ yr^{-1}$)
1	Banteay Mean Cheay	197
2	Battambang	4,429
3	Kampong Speu	677
4	Kampong Thom	511
5	Kampot	2,184
6	Kandaal	131
7	Kep*	-
8	Koh Kong	2,576
9	Kompong Cham	906
10	Kompong Chnang	122
11	Kratie	394
12	Krong Preah Sihanouk	1,329
13	Mondul Kiri	452
14	Otdar Mean Chey	132
15	Pailin	1,987
16	Phnom Penh	4
17	Preah Vih	400
18	Prey Veaeng	32
19	Pursat	2,796
20	Ratana Kiri	500
21	Siem Reap	323
22	Stung Treng	562
23	Svaay Rieng	30
24	Takeo	26
	Cambodia	**20,700**

** No annual emissions from deforestation for this province*

3.2 FACTORS FOR NATIONAL CIRCUMSTANCES

This section illustrates the factors that are often used to explain patterns of deforestation across Cambodia. All factors are extracted as subsets from the regional data presented in the regional chapter (section 3.2). Maps of elevation, roads, settlements (populated places), climate zones, soil nutrient availability, protected areas and rural population growth are shown in Figures C-6-12.

3.2.1 Elevation

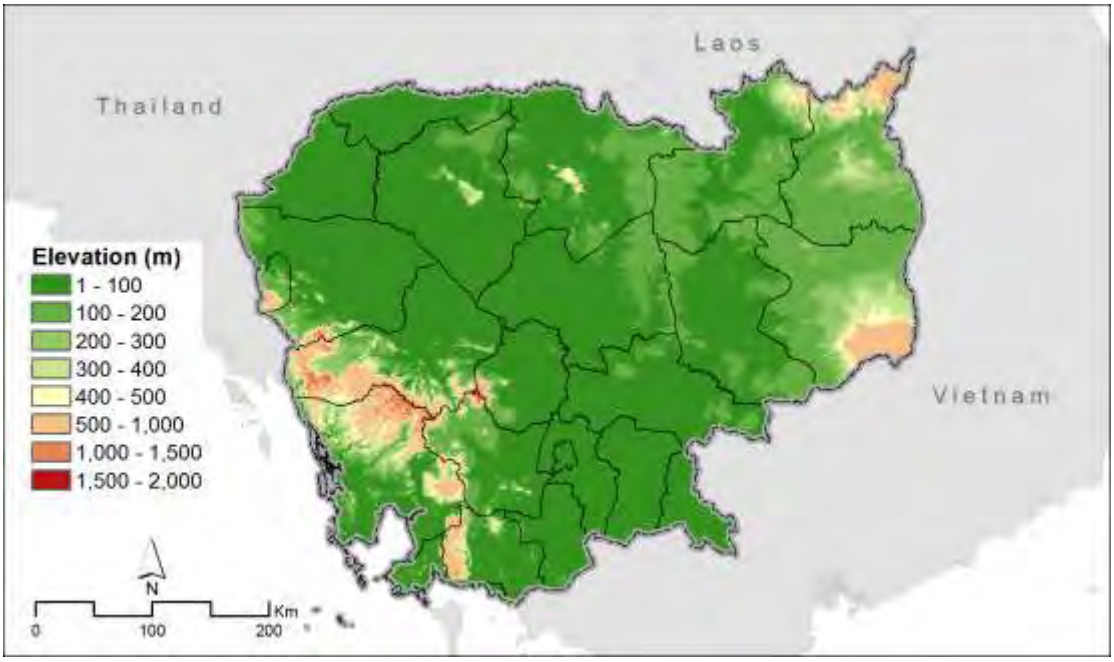


Figure C-6. Elevation across Cambodia.

3.2.2 Roads

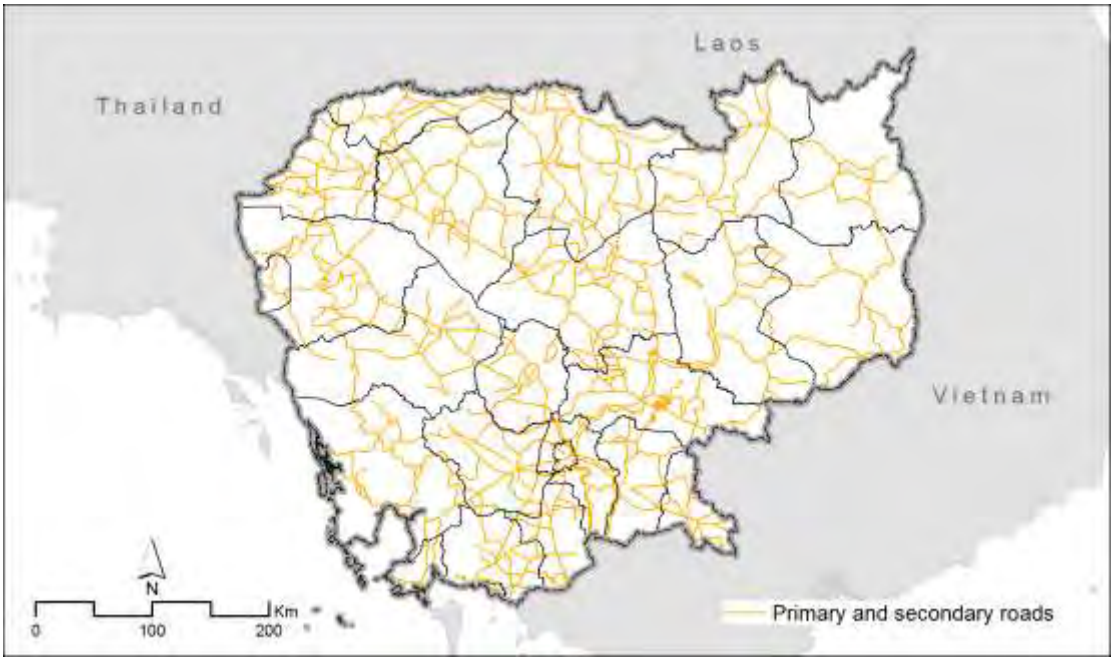


Figure C-7. Location of roads in Cambodia.

3.2.3 Settlements

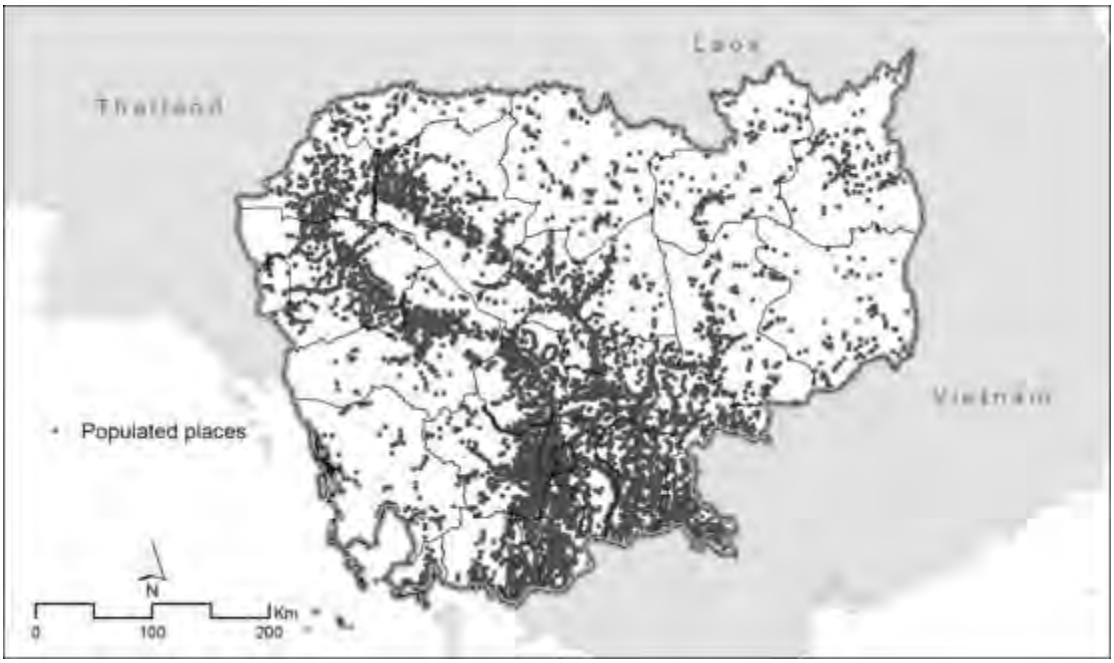


Figure C-8. Map of all settlements (populated places) in Cambodia.

3.2.4 Climate

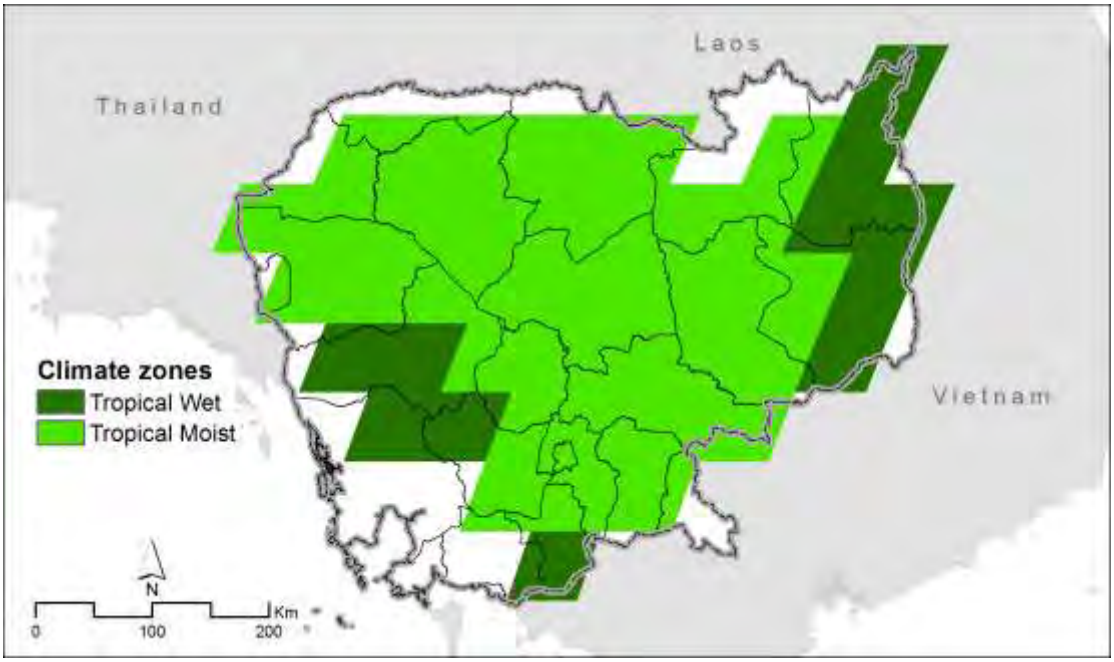


Figure C-9. Map of Climate zones across Cambodia.

3.2.5 Soil nutrient availability

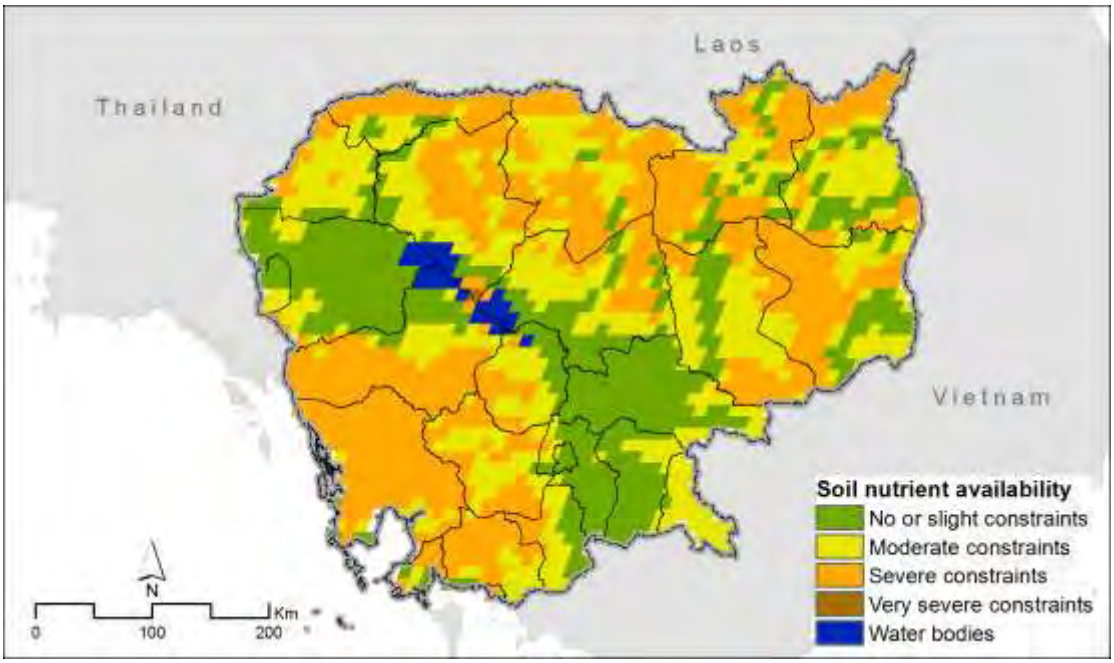


Figure C-10.Map of areas with soil nutrient availability across Cambodia.

3.2.6 Rural population growth

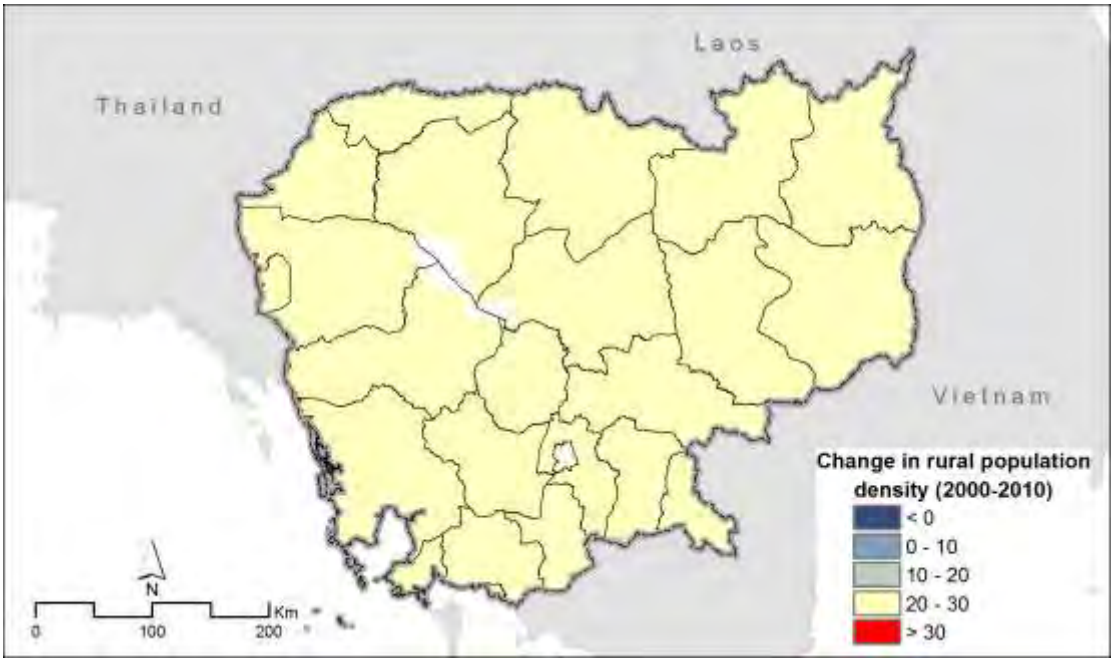


Figure C-11. Rural population growth shown as percent population density.

3.2.7 Protected areas

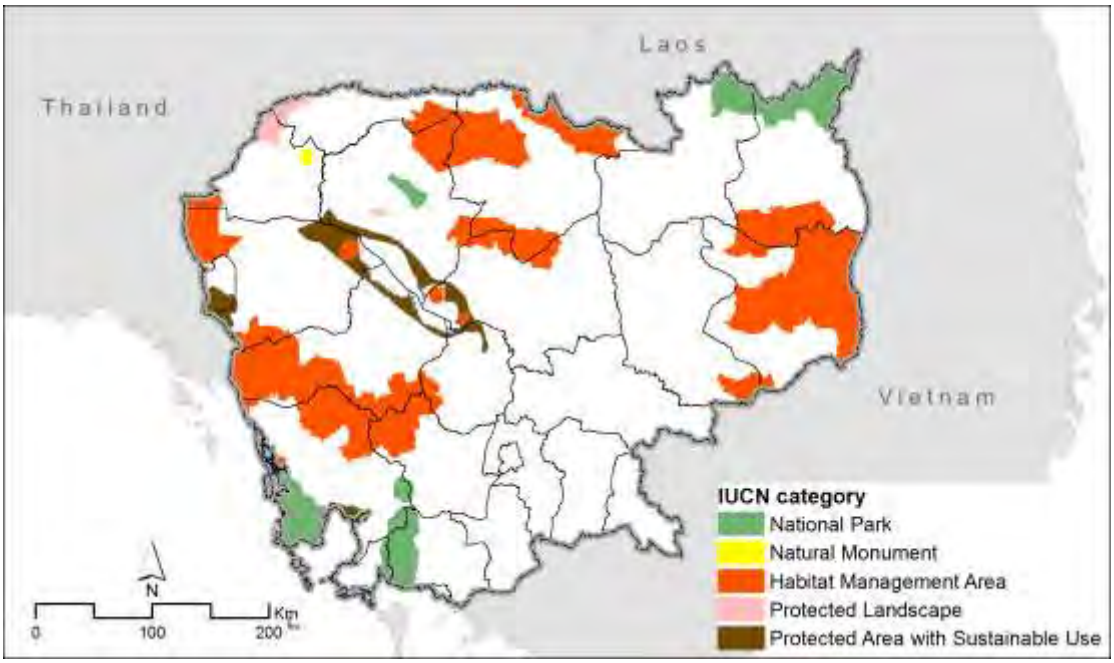


Figure C-12. Map of Protected Areas by IUCN category.

3.3 FOREST THREATS

This section presents spatial overlays of different factors compared to the 2002 forest cover map. These illustrate possible threats to the forest and areas with potential for future deforestation in Cambodia. Coarse resolution global datasets were used to present the factors, so while some maps may not appear to be high resolution, these spatial overlays provide an illustration of how different threat for forests can be mapped with country-specific data.

3.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forest to other land uses depends on the amount carbon stored in the forest. Understanding where forests with high carbon stocks, and thus potential for high emissions from deforestation, are located within Cambodia could provide input to decision-makers focused on land use planning in the country.

Figure C-13 illustrates the distribution of carbon stocks categories across forests in Cambodia. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH 200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}). Table C-13 reports the percent forest per carbon stock category for provinces in Cambodia.

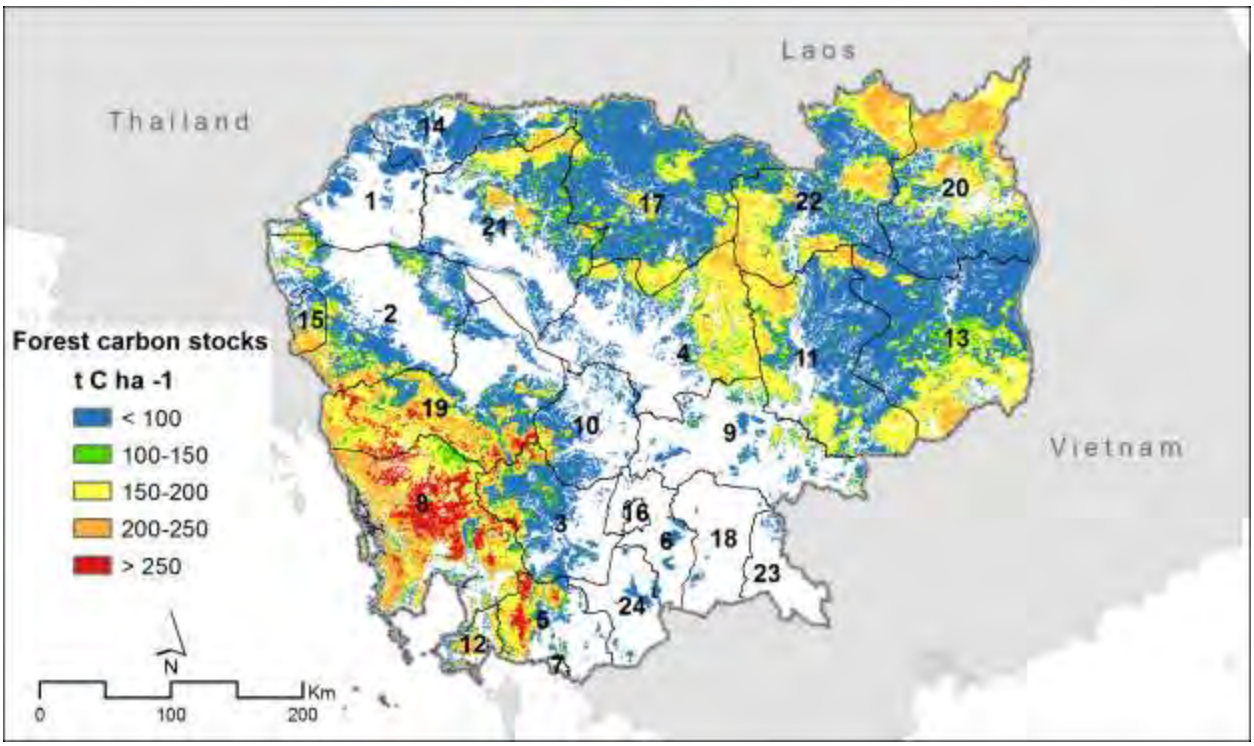


Figure C-13. Forest carbon stocks for forest cover in 2002 across Cambodia. Provinces are labeled according to 'Map ID' information provided in Table 6.

The largest portion of forests was classified in LOW carbon category (49%), followed by the MEDIUM HIGH carbon category (25%) and the least area of the forest was classified in VERY HIGH carbon category (3%).

Table C-6. Sub-national estimates as percent forest cover per carbon stock category. Carbon stocks categories are defined as LOW (< 100 t C ha-1), MEDIUM (100-150 t C ha-1), MEDIUM HIGH (150-200 t C ha-1), HIGH (200-250 t C ha-1) and VERY HIGH (< 250 t C ha-1).

Map ID	Provinces	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
1	Banteay Mean Cheay	151	-	1	5	4	90
2	Battambang	565	1	10	17	14	59
3	Kampong Speu	403	3	11	14	10	62
4	Kampong Thom	623	-	11	47	10	33
5	Kampot	232	15	17	31	10	27
6	Kandaal	31	-	-	1	4	95
7	Kep	3	-	-	16	7	77
8	Koh Kong	959	24	30	28	8	10
9	Kompong Cham	173	0	2	16	18	64
10	Kompong Chnang	209	1	5	6	5	83
11	Kratie	922	0	7	30	9	54
12	Krong Preah Sihanouk	72	1	28	22	11	38
13	Mondul Kiri	1,193	-	5	26	12	58
14	Otdar Mean Chey	353	-	10	12	6	72
15	Pailin	86	1	29	32	10	28
16	Phnom Penh		-	-	-	-	-
17	Preah Vih	1,291	-	4	14	10	72
18	Prey Veaeng	9	-	-	-	-	100
19	Pursat	865	8	22	34	8	28
20	Ratana Kiri	928	-	18	30	8	44
21	Siem Reap	634	-	9	20	12	59
22	Stung Treng	1,026	-	17	33	9	41
23	Svaay Rieng	12	-	0	2	8	90
24	Takeo	29	0	0	1	1	98
	Cambodia	**10,769**	**3**	**13**	**25**	**10**	**49**

3.3.2 Analysis #2: Forest and agriculture suitability

Most forests are cleared for agriculture (small or large scale) and soil nutrient availability is a factor that could be used to predict future threat to the forest. Figure C-14 illustrates the potential suitability for agriculture across the forest in 2002 based on nutrient availability in the soils. Forests with slight to moderate constraint based on soil nutrient availability were considered more suitable, while forests with severe and very severe constraints were considered not suitable for agriculture. Figure C-15 illustrates the distribution of the carbon stock categories across forests with potential suitability for agriculture use.

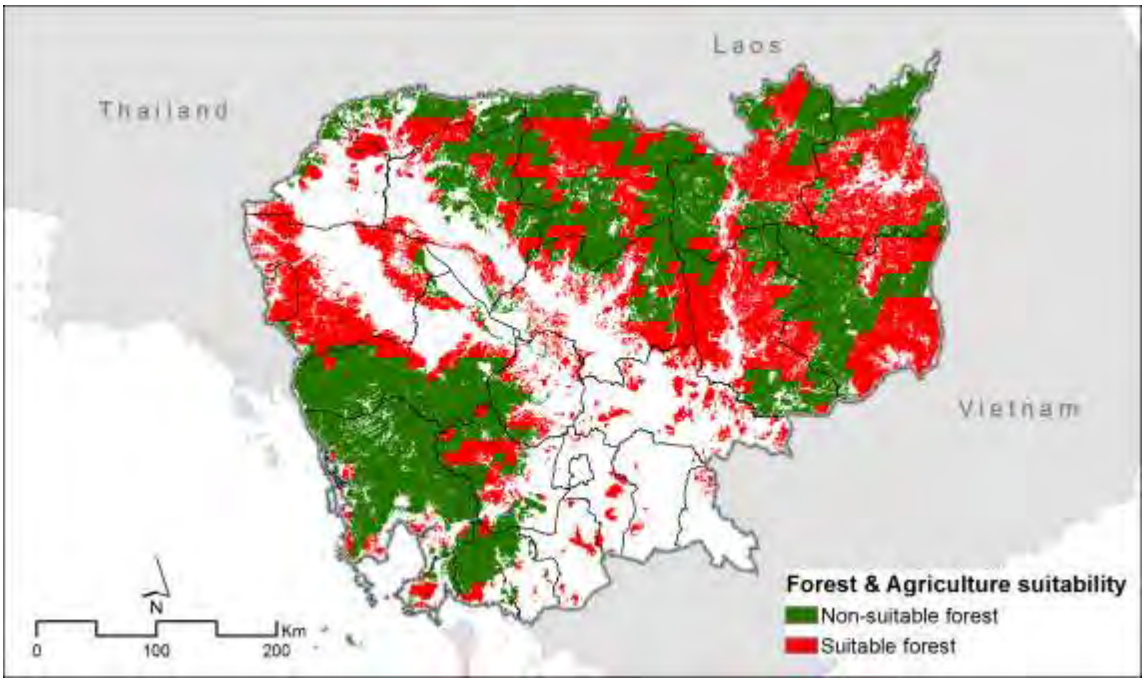


Figure C-14. Spatial overlay of forests areas in 2002 with no or slight to moderate constraint (red) and with high and very high (green) constraints on soil nutrient availability for Cambodia.

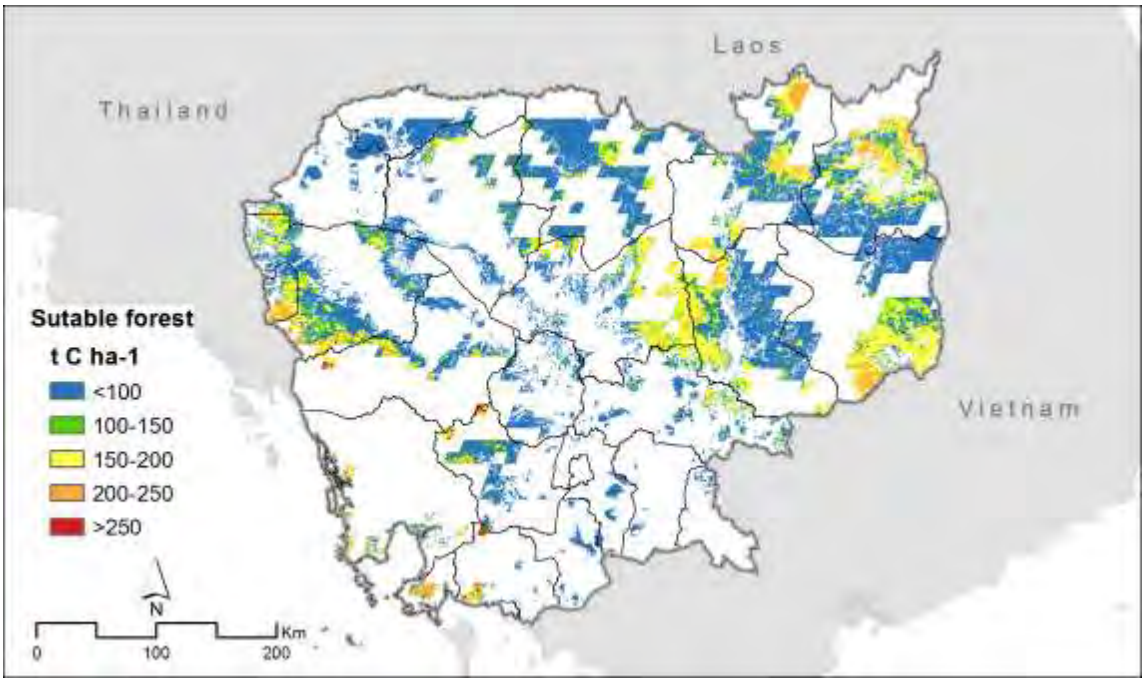


Figure C-15. Spatial overlay of forest lands suitable for agriculture and their respective forest carbon stocks.

3.3.3 Analysis #3: Forest and road network

Forests close to roads are more likely to be deforested or disturbed than forests further away from roads. Using the assumption that forest within 5km of roads is more accessible, Figure C-16 illustrates forests more and less accessible by roads in Cambodia. Figure C-17 illustrates the distribution of carbon stock categories across the more accessible forest, as defined within the 5 km buffer zone around the roads.

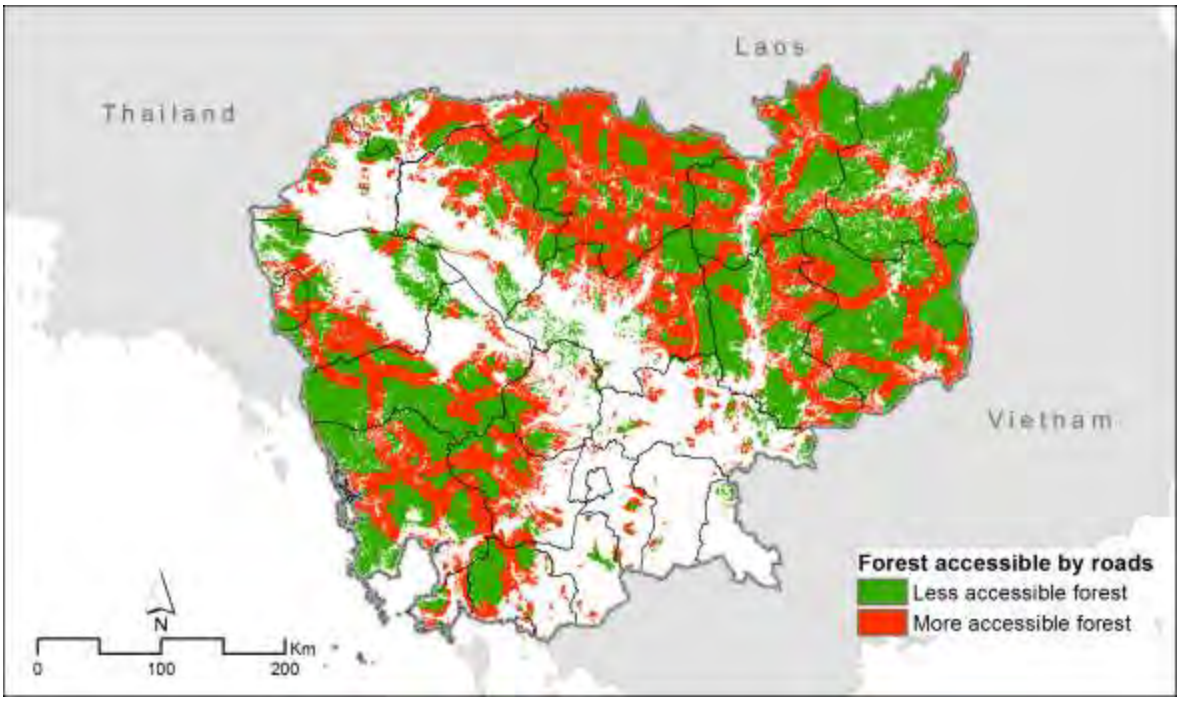


Figure C-16. Spatial overlay of forest cover in 2002 and 5 km buffer zone around road network in Cambodia. More accessible forests are defined as forests within 5 km buffer zone and less accessible forests are defined as those outside this zone.

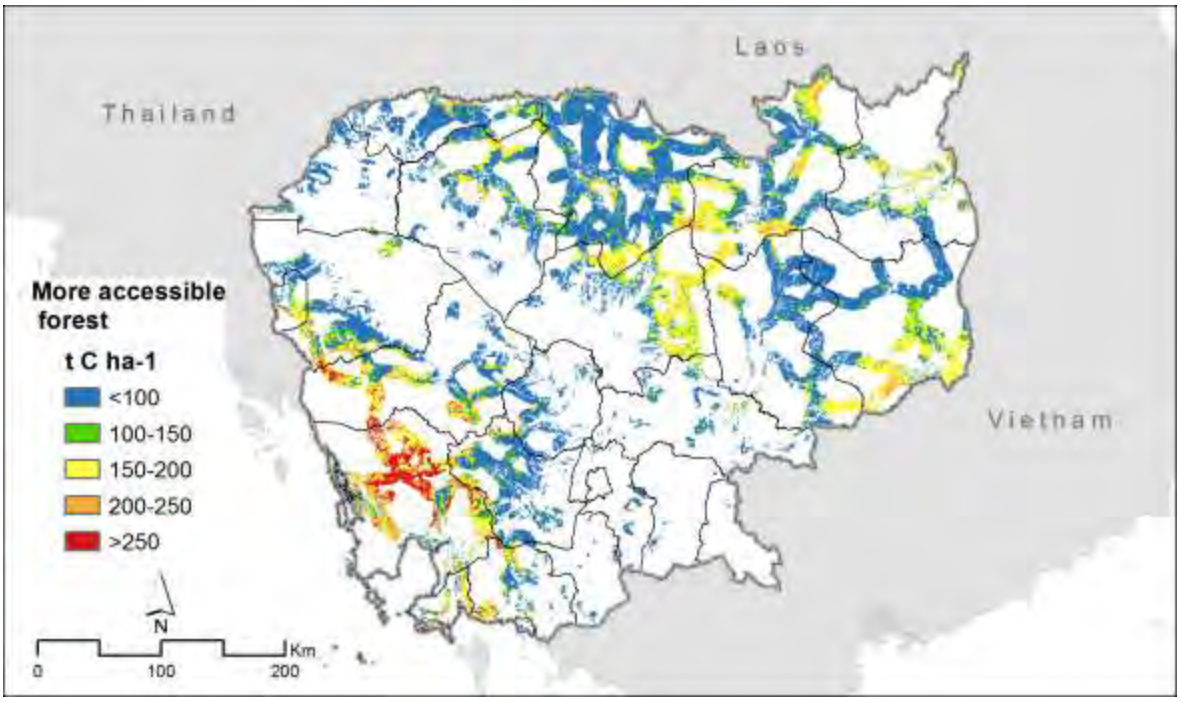


Figure C-17. Spatial overlay of more accessible forest (within 5 km buffer zone around roads) and carbon stocks.

3.3.4 Analysis #4: Forest and change in population

An increase in rural population could lead to increased potential threats to forests. Figure C-18 illustrates the change in population density based on the Gridded Population of the World (GPWv3).[3] Most of the rural area in Cambodia experienced a change of population density greater the 25%, which falls in the 20-30% change category. If country-specific data on population are available, such an overlay could provide more detailed information about provinces experiencing rapid change in population density that could present a threat to their forests.

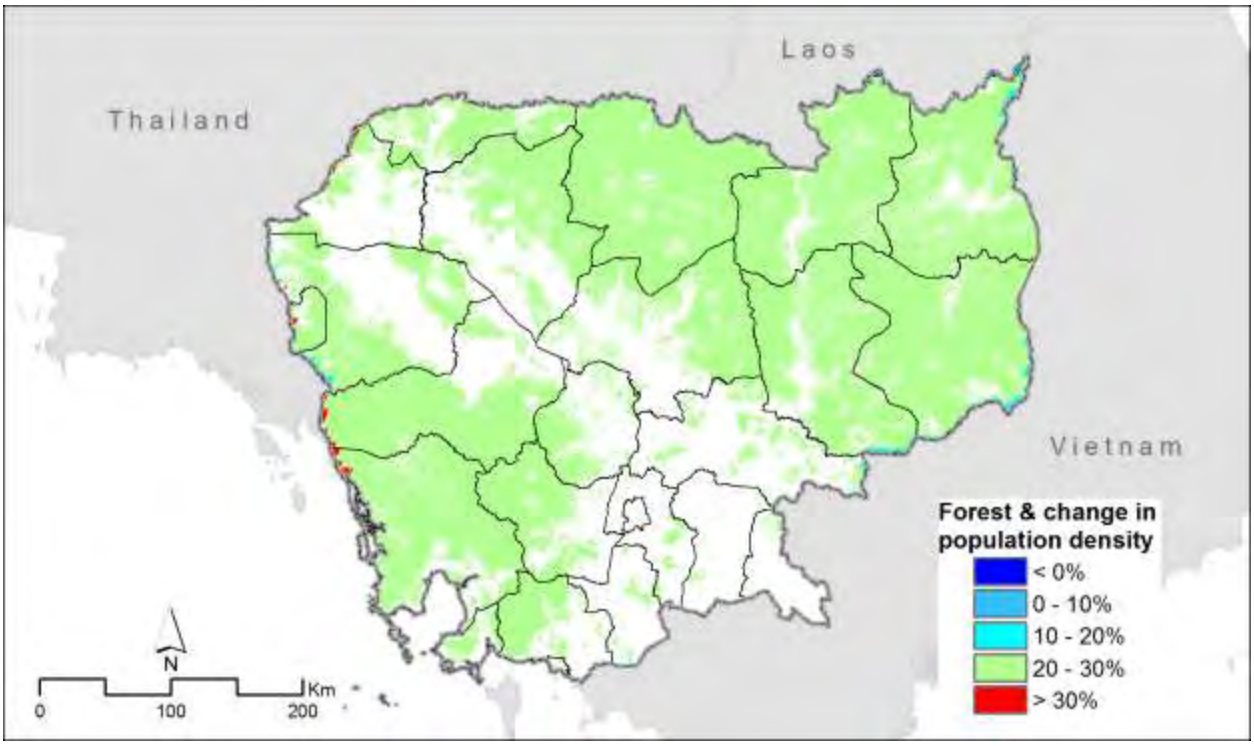


Figure C-18. Spatial overlay of forest cover and change in rural population density between 2000 and 2010.

[3] Note that this does not necessarily reflect actual population growth data based on Cambodia census data.

3.3.5 Analysis #5: Forest and elevation

Deforestation often occurs at low elevation where people generally prefer to live. Most of the forest in Cambodia is located at low elevation (Figure C-19). Forests at moderate elevation are concentrated in the northeast, southeast and midwestern areas of the country, while the forests at high elevation are located in the midwestern part of the country.

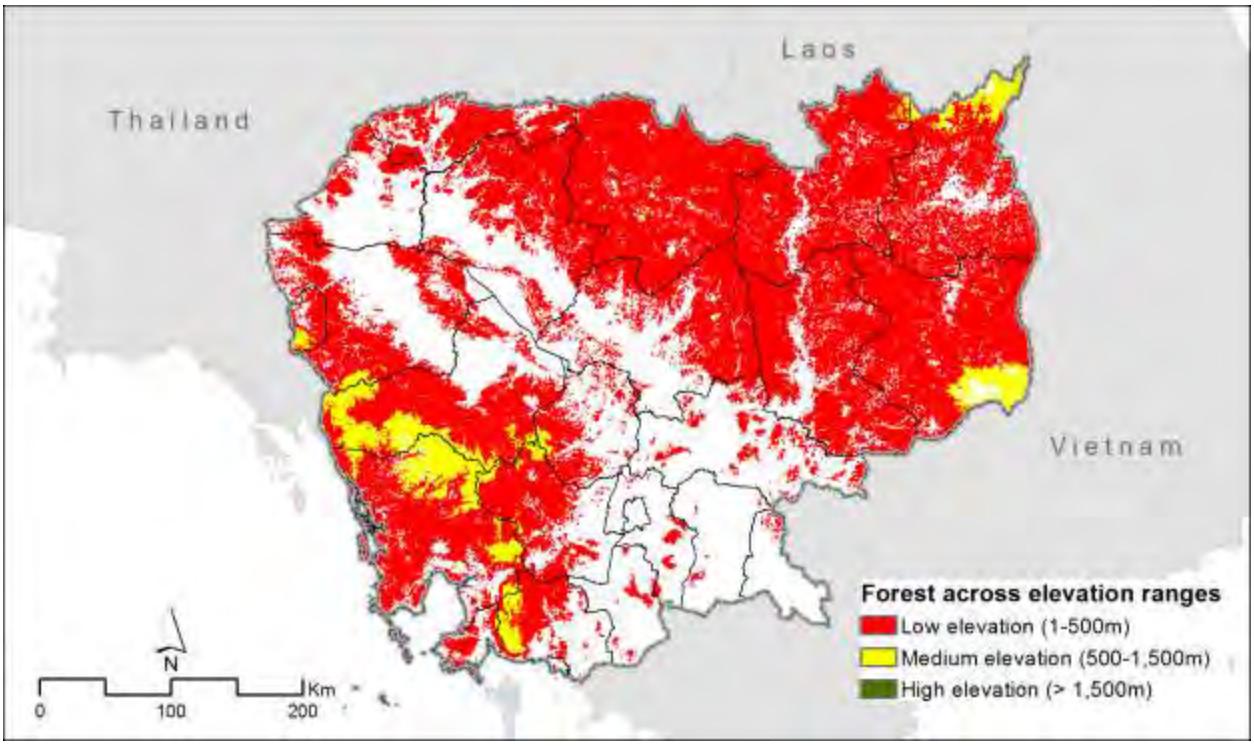


Figure C-19. Forest cover in Cambodia for 2002 by elevation classes.

4. LAOS

This section presents the same maps and statistics given in the South and Southeast Asia Atlas (Chapter 2) reported at the subnational level for Laos. These highlight key factors that should be considered for defining national circumstances, and illustrate forest threats based on roads, change in population density, elevation and suitability for agriculture based on nutrient availability.

4.1 NATIONAL STATISTICS RELATED TO REDD+

4.1.1 Forest cover

Figure L-1 shows the extent of forest cover in 2000 across the provinces in Laos and Table L-1 reports the forest coverage per province and percent of the province area covered by forest.

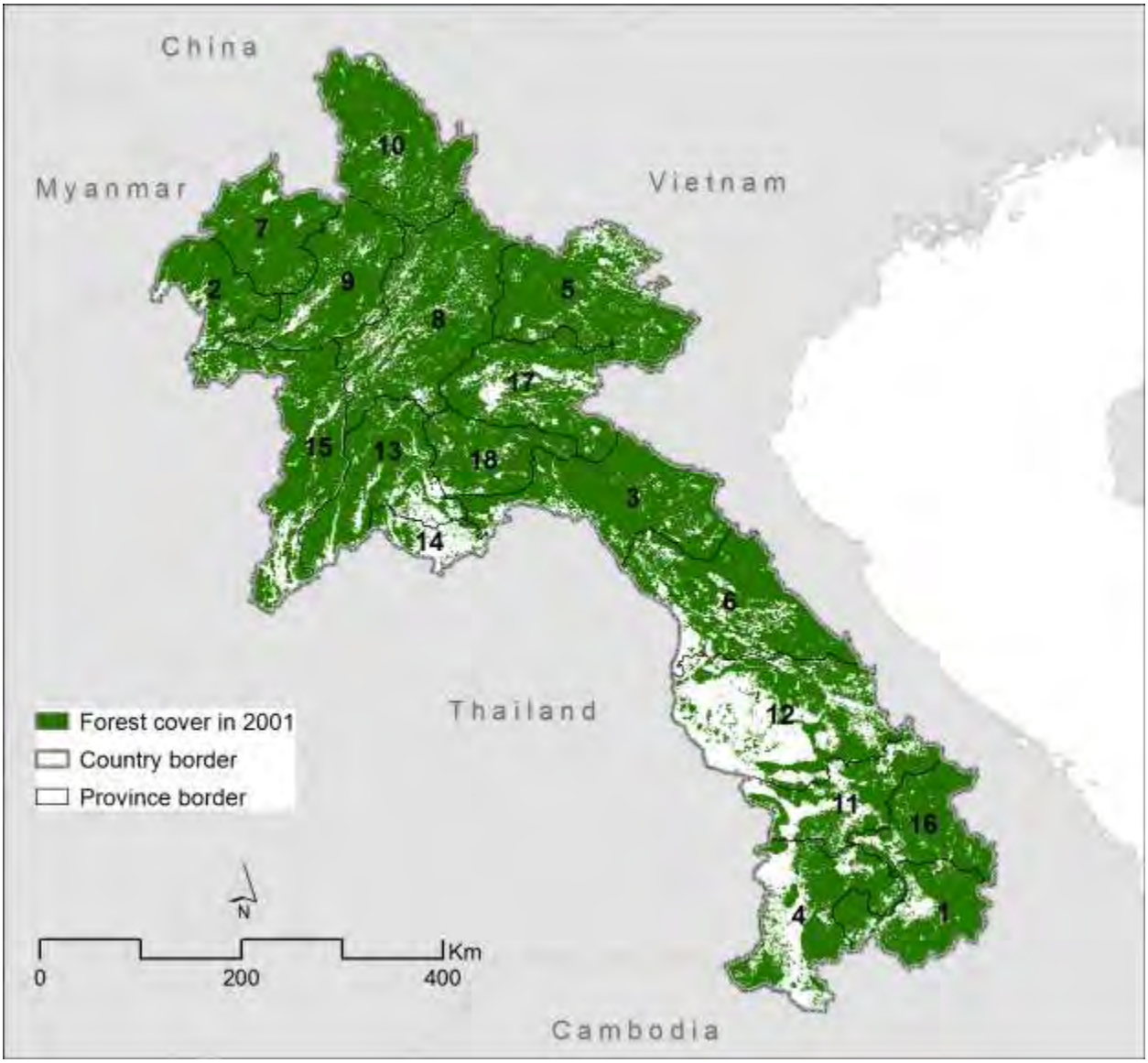


Figure L-1. Forest cover in 2000 across Laos. Forest cover is defined greater than 25% tree cover from MODIS VCF data. Provinces are labeled according to 'Map ID' information provided in Table L-1.

According to spatial data, Louang Namtha province has the largest extent of forest cover (94%), while Vientiane Prefecture has the least extent of forest cover (35 %).

Table L-1. Province level estimates of forests and percent of province area in forest cover for 2000

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
1	Attapu	954	824	86%
2	Bokeo	688	597	87%
3	Bolikhamxai	1,587	1,420	89%
4	Champasak	1,496	936	63%
5	Houaphan	1,735	1,504	87%
6	Khammouan	1,660	1,317	79%
7	Louang Namtha	982	924	94%
8	Louangphrabang	2,002	1,727	86%
9	Oudomxai	1,181	1,035	88%
10	Phongsali	1,539	1,416	92%
11	Saravan	1,021	676	66%
12	Savannakhet	2,149	967	45%
13	Vientiane	1,256	976	78%
14	Vientiane Prefecture	363	126	35%
15	Xaignabouri	1,565	1,281	82%
16	Xekong	838	768	92%
17	Xiangkhoang	1,267	1,016	80%
18	Xaisomboun	776	699	90%
	Laos	**23,060**	**18,209**	**79%**

4.1.2 Forest Cover in Protected Areas

Figure L-2 illustrates the forest area in protected areas and Table L-2 reports the actual forest area and percent forest in protected area per province.

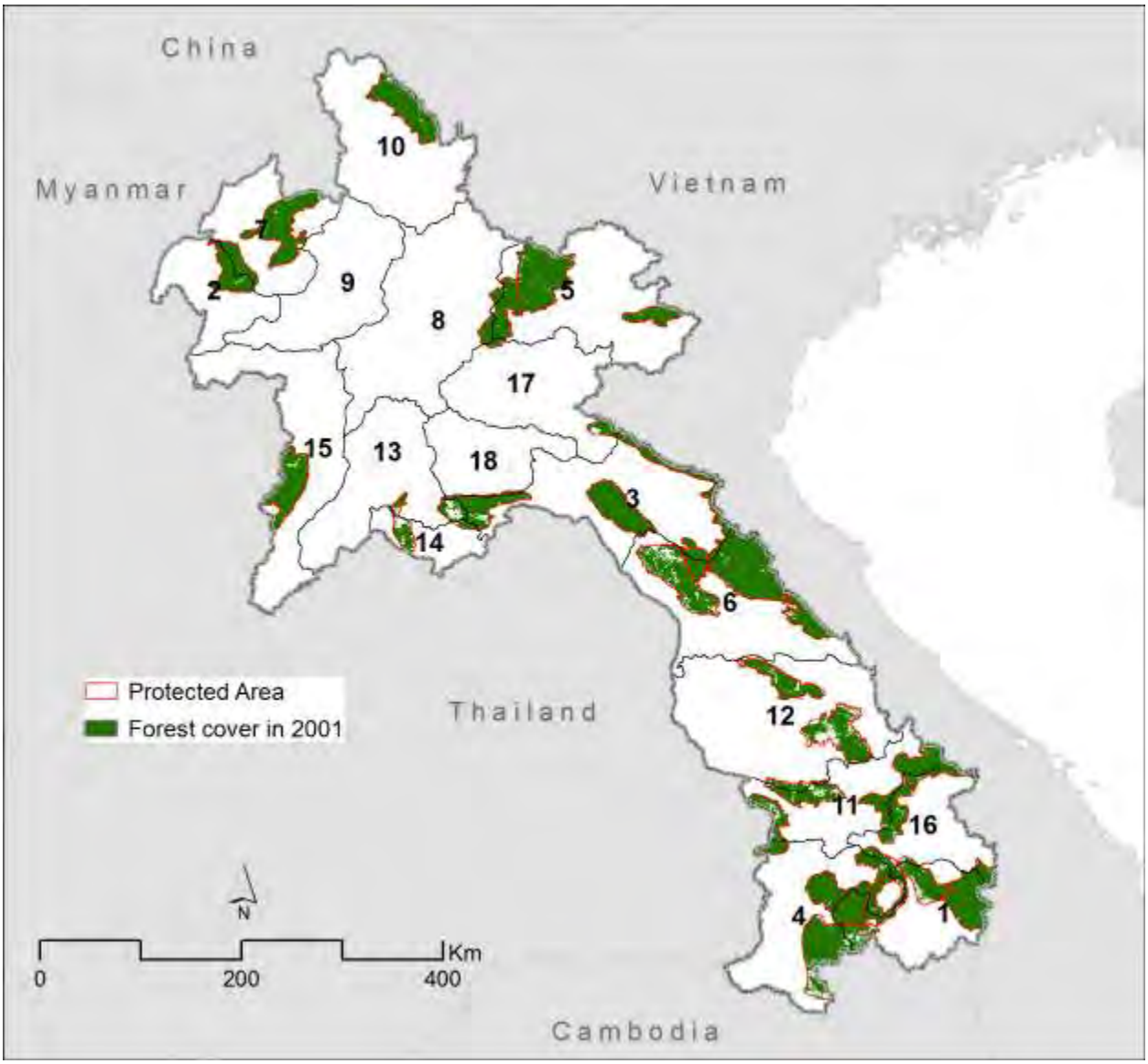


Figure L-2. Distribution of forest cover in 2000 within protected area across Laos. Provinces are labeled according to 'Map ID' information provided in Table L-2.

The province with the highest percent forest in protected area is Attapu province (50%), with 416,000 ha protected forest. The provinces with at least percent forest in protected area are Louangphrabang (2%) and Xaisomboun province (2%), with 42,000 ha and 16,000 ha protected forest, respectively. Oudomxai province does not have any protected forests.

Table L-2. Province level estimates of forests in protected areas and percent protected forests of the total forest area in Laos.

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
1	Attapu	416	50%
2	Bokeo	88	15%
3	Bolikhamxai	428	30%
4	Champasak	422	45%
5	Houaphan	416	28%
6	Khammouan	635	48%
7	Louang Namtha	269	29%
8	Louangphrabang	42	2%
9	Oudomxai*	0	0%
10	Phongsali	179	13%
11	Saravan	277	41%
12	Savannakhet	282	29%
13	Vientiane	42	4%
14	Vientiane Prefecture	49	39%
15	Xaignabouri	177	14%
16	Xekong	16	2%
17	Xiangkhoang	197	19%
18	Xaisomboun	41	6%
	Laos	**3,975**	**22%**

4.1.3 Gross Forest Cover Loss

The annual gross forest cover loss between 2000 and 2005 is shown in Figure L-3, with a summary of the actual values presented in Table L-3.

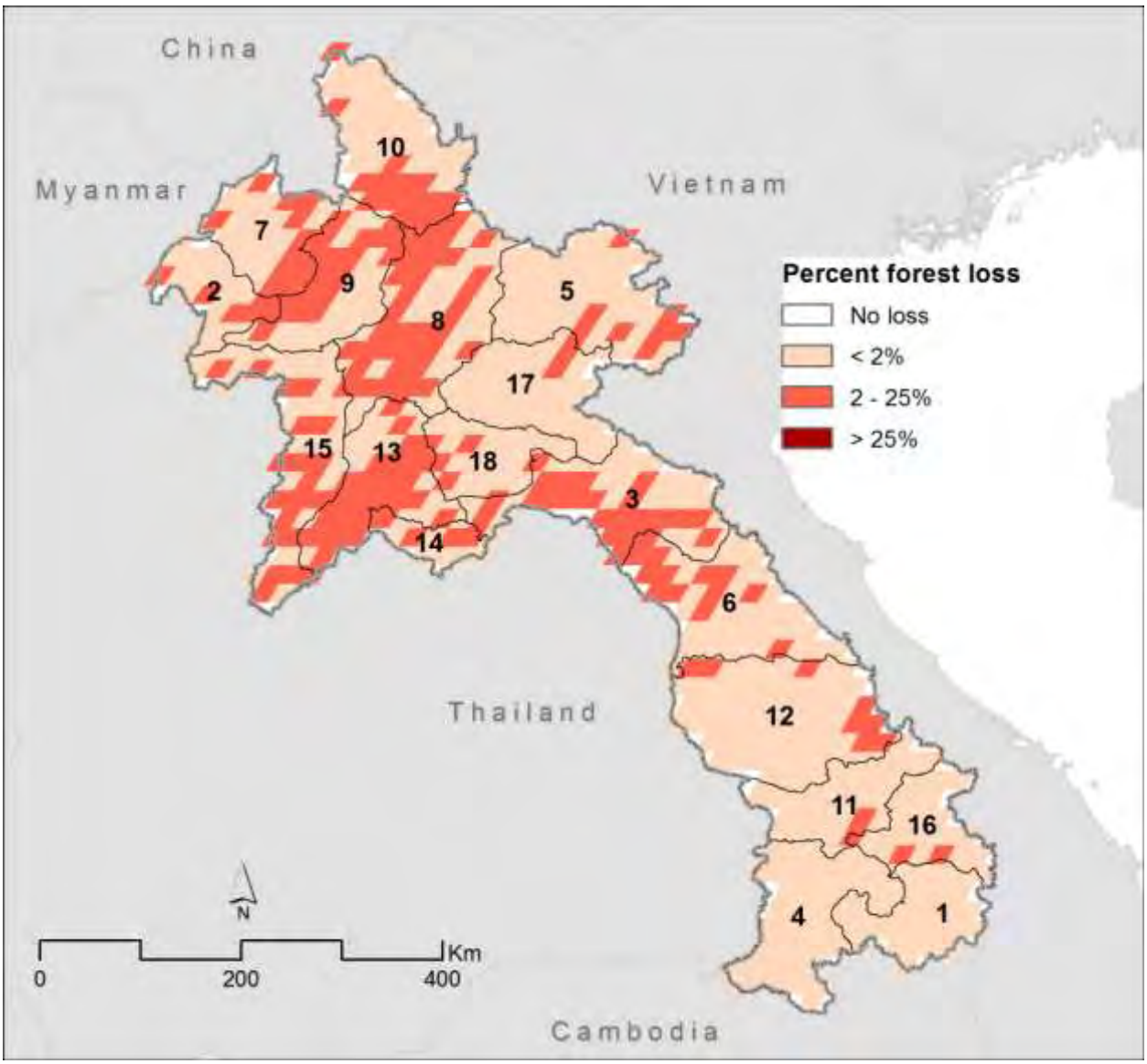


Figure L-3. Distribution of gross forest cover loss between 2000 and 2005 across Laos. Provinces are labeled according to 'Map ID' information provided in Table 3.

Vientiane Prefecture and Vientiane provinces had the highest gross forest loss expressed as a percent of the initial forests in 2000, 1.2% and 1.3% respectively. Six provinces had 0.2%, the lowest gross forest loss expressed as a percent of the initial forests in 2000.

Table L-3. Province level estimates of average annual gross forest cover loss between 2000 and 2005 expressed in hectares and percent of the forest cover in 2000

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
1	Attapu	1,381	0.2%
2	Bokeo	1,982	0.3%
3	Bolikhamxai	9,685	0.7%
4	Champasak	1,685	0.2%
5	Houaphan	4,633	0.3%
6	Khammouan	5,555	0.4%
7	Louang Namtha	4,311	0.5%
8	Louangphrabang	10,766	0.6%
9	Oudomxai	6,692	0.6%
10	Phongsali	5,782	0.4%
11	Saravan	1,604	0.2%
12	Savannakhet	4,319	0.4%
13	Vientiane	11,865	1.2%
14	Vientiane Prefecture	1,674	1.3%
15	Xaignabouri	8,154	0.6%
16	Xekong	1,721	0.2%
17	Xiangkhoang	2,460	0.2%
18	Xaisomboun	1,695	0.2%
	Laos	**85,965**	**0.5%**

4.1.4 Biomass Carbon Stocks

Figure L-4 illustrates the distribution of biomass carbon stocks within Laos.

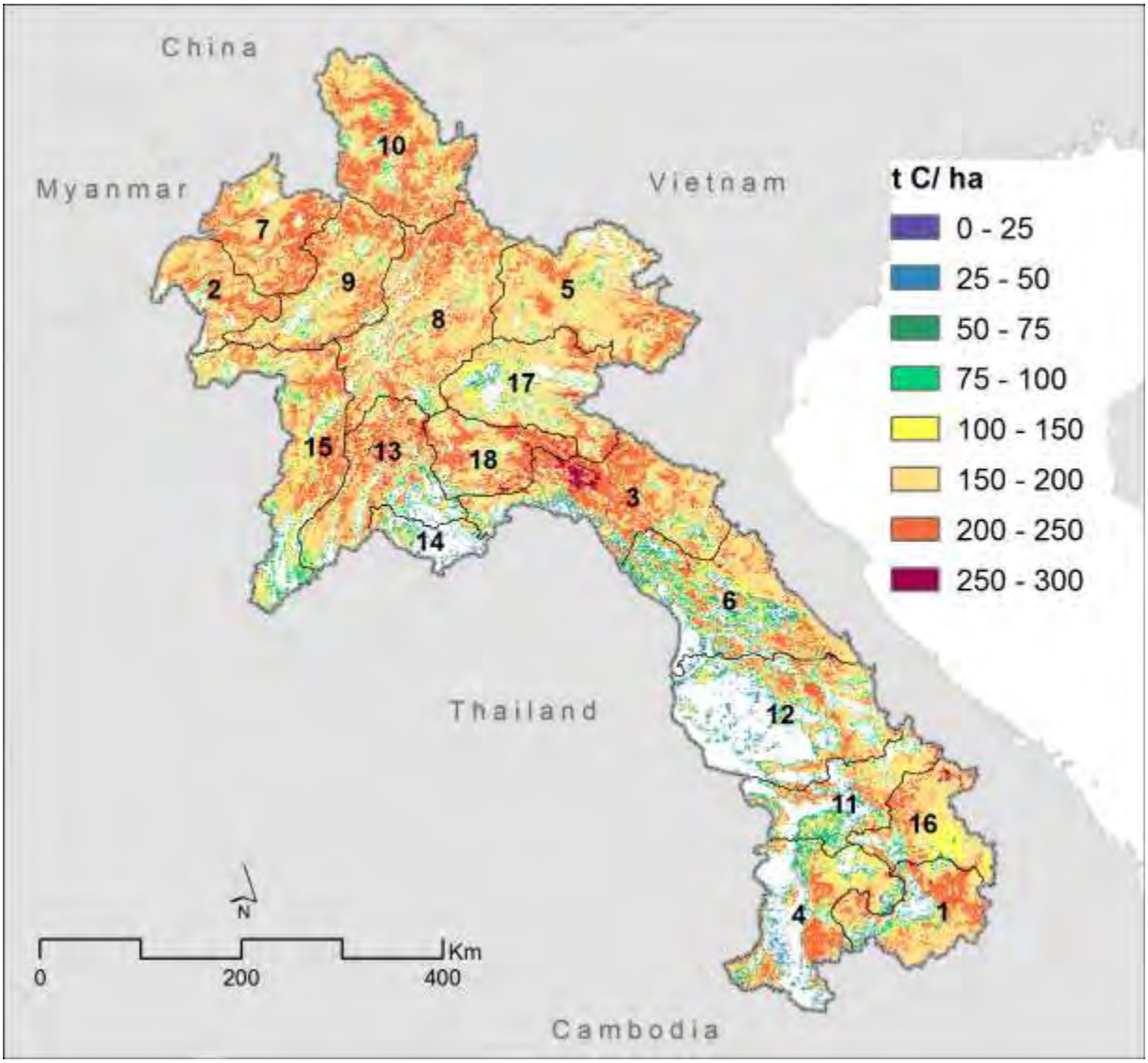


Figure L-4. Distribution of above and belowground forest biomass carbon stocks across Laos. Provinces are labeled according to 'Map ID' information provided in Table L-4.

The forests in Xaisomboun and Louang Namtha province were with highest area weighted carbon stocks (188 t C ha^{-1}), while forests in Vientiane Prefecture were with the lowest area weighted carbon stocks (120 t C ha^{-1}). The total forest carbon stock for the forest in 2000 was estimated at 3,111 Million t C, with Louangphrabang province contributing the most with 310 Million t C, and Vientiane Prefecture contributing the least to the total forest carbon stocks with 15 Million t C.

Table L-4. Province level estimates of above and belowground forest biomass carbon stocks expressed as area weighted average (t C ha^{-1}) and total carbon (t C).

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Million t C)
1	Attapu	175	145
2	Bokeo	186	111
3	Bolikhamxai	181	257
4	Champasak	150	140
5	Houaphan	175	263
6	Khammouan	151	199
7	Louang Namtha	188	173
8	Louangphrabang	180	310
9	Oudomxai	178	185
10	Phongsali	183	260
11	Saravan	148	100
12	SavannakhΘt	144	139
13	Vientiane	175	170
14	Vientiane Prefecture	120	15
15	Xaignabouri	168	215
16	Xekong	170	130
17	Xiangkhoang	166	168
18	Xaisomboun	188	131
	Laos	**168**	**3,111**

4.1.5 Carbon emissions from deforestation

Annual carbon emissions from deforestation between 2000 and 2005 for Laos are shown in Figure L-5. Table L-5 reports the annual emissions from deforestation per province.

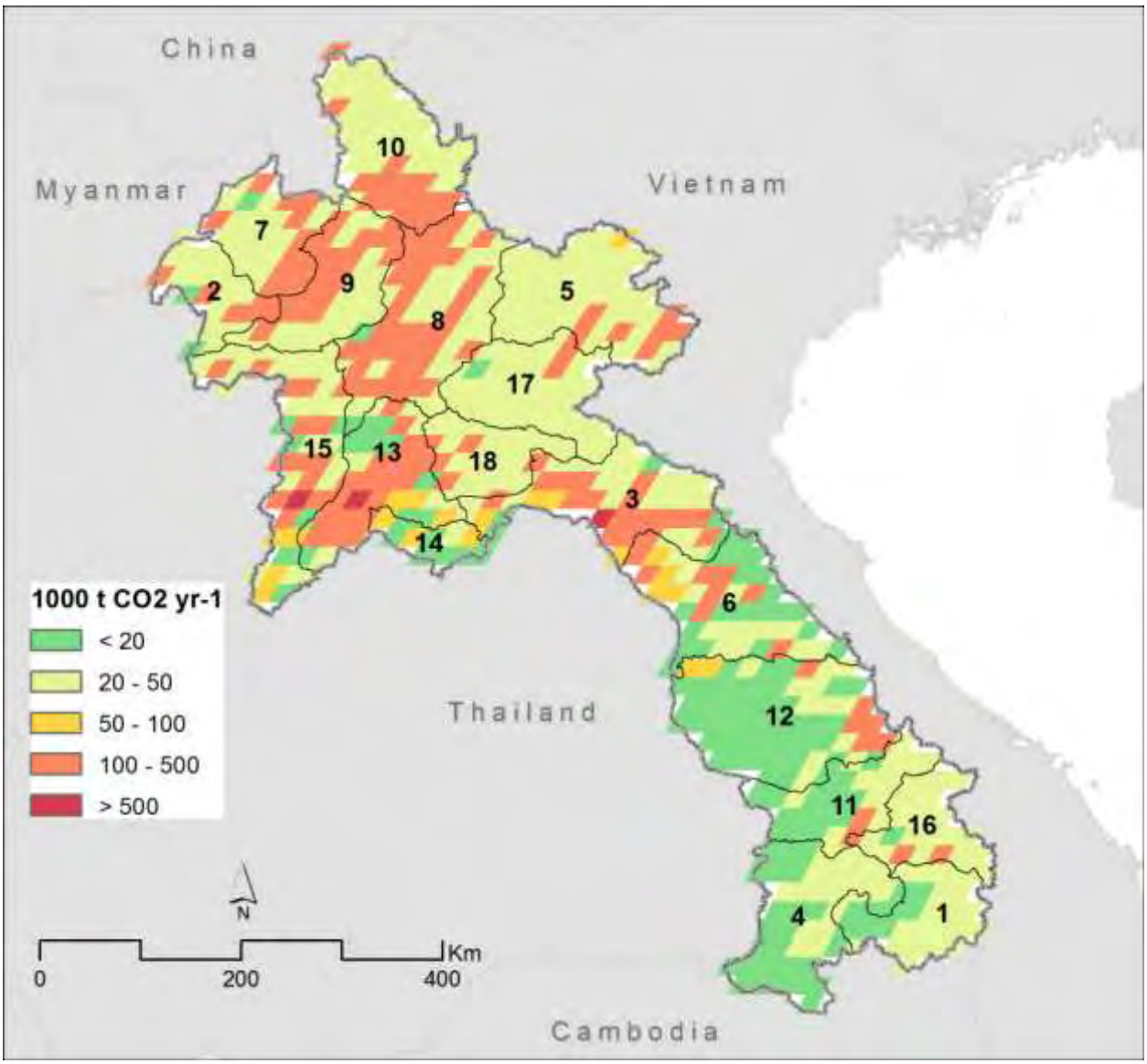


Figure L-5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005 for Laos. Provinces are labeled according to 'Map ID' information provided in Table 5.

Louangphrabang province was found to have the highest annual CO_2 emissions from deforestation (6,596,000 t CO_2 yr^{-1}), followed by Vientiane and Bolikhamxai province with 5,700,000 t CO_2 yr^{-1} and 5,558,000 t CO_2 yr^{-1}, respectively. Vientiane Prefecture was found to have the lowest annual CO_2 emissions of deforestation between 2000 and 2005 (358,000 t CO_2 yr^{-1}).

Table L-5. Province level estimates of carbon emissions (t CO_2 yr^{-1}) from deforestation between 2000 and 2005.

Map ID	Province	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
1	Attapu	885
2	Bokeo	1,308
3	Bolikhamxai	5,558
4	Champasak	753
5	Houaphan	2,960
6	Khammouan	2,261
7	Louang Namtha	3,028
8	Louangphrabang	6,596
9	Oudomxai	3,887
10	Phongsali	3,925
11	Saravan	828
12	Savannakhet	1,682
13	Vientiane	5,700
14	Vientiane Prefecture	358
15	Xaignabouri	3,562
16	Xekong	1,098
17	Xiangkhoang	1,585
18	Xaisomboun	1,153
	Laos	**47,128**

4.2 FACTORS FOR NATIONAL CIRCUMSTANCES

This section illustrates the factors that are often used to explain patterns of deforestation across Laos. All factors are subsets from the regional factors presented in the regional Atlas (section 3.2). Maps of elevation, roads, settlements (populated places), climate zones, soil nutrient availability, protected areas and rural population growth are shown in Figures L-6-12.

4.2.1 Elevation

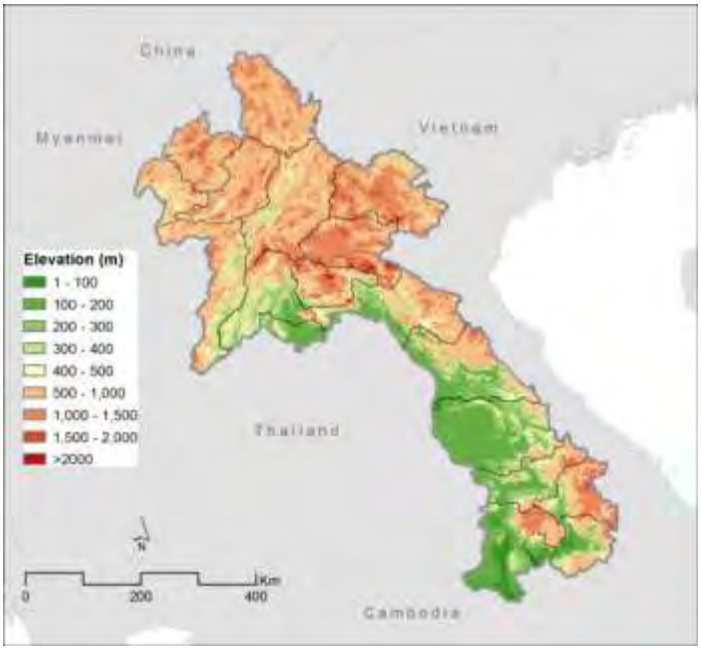


Figure L-6. Elevation across Laos.

4.2.2 Roads

Figure L-7. Location of roads across Laos.

4.2.3 Settlements

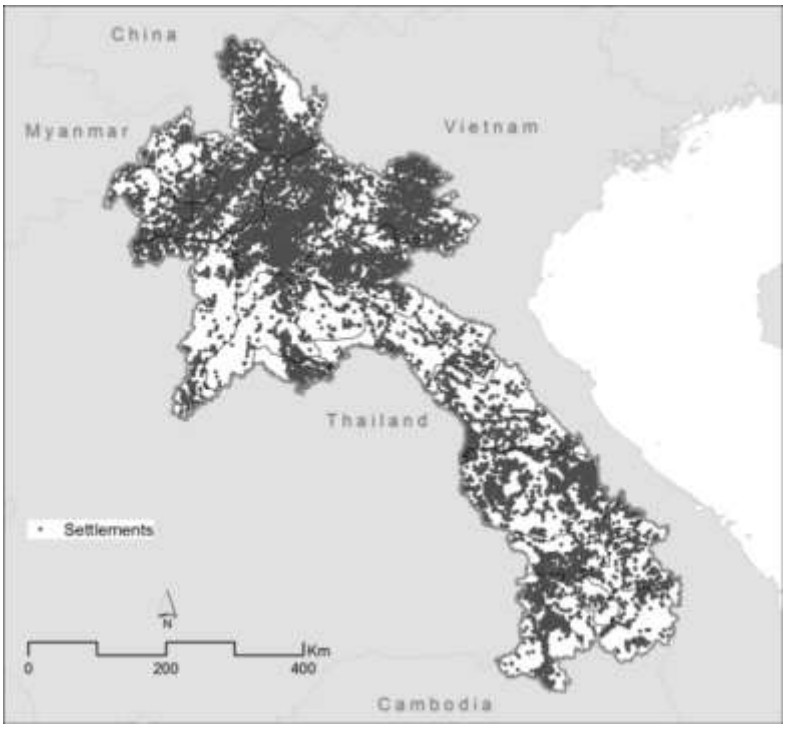


Figure L-8. Map of all settlements (populated places) for Laos.

4.2.4 Climate

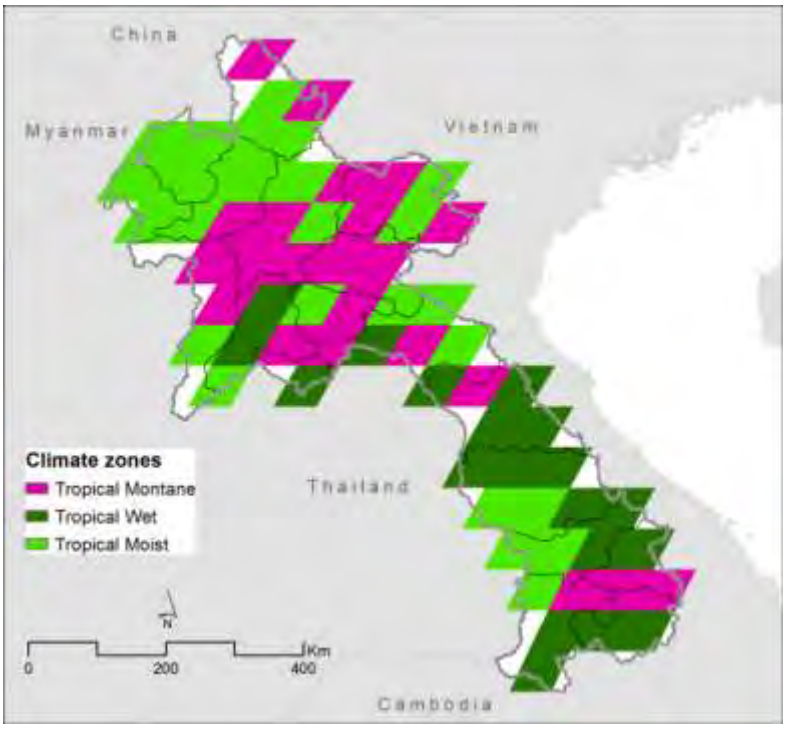


Figure L-9. Map of Climate zones across Laos.

4.2.5 Soil nutrient availability

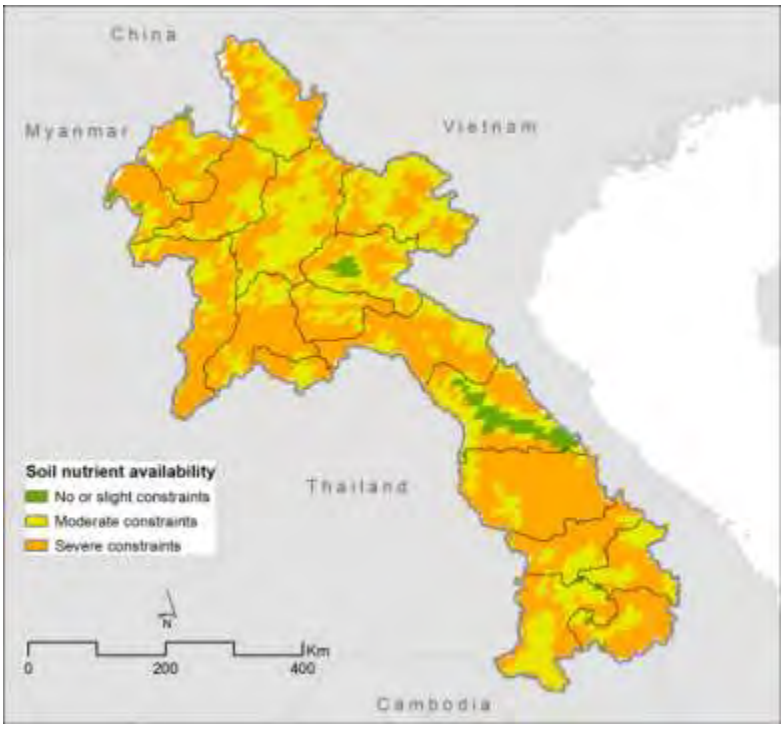


Figure L-10.Map of areas with soil nutrient availability across Laos.

4.2.6 Rural population growth

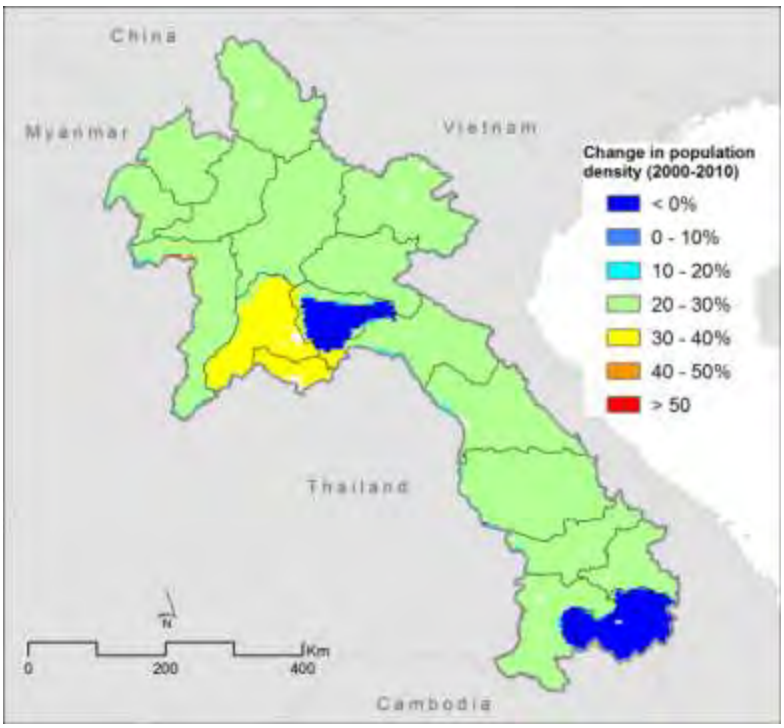


Figure L-11. Rural population growth shown as percent change of population density.

4.2.7 Protected areas

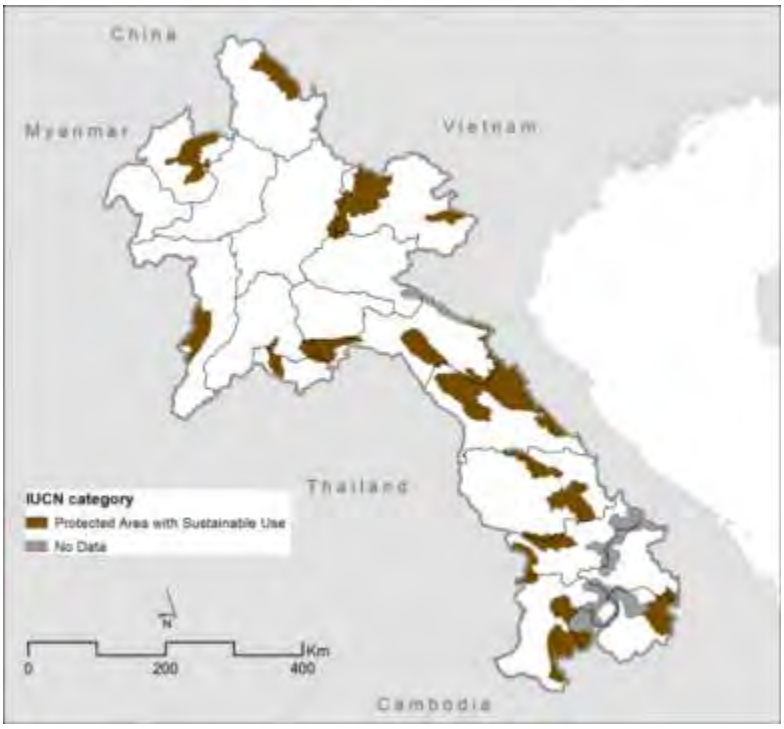


Figure L-12. Map of Protected Areas by IUCN category.

4.3 FOREST THREATS

This section presents spatial overlays of different factors over the 2000 map of forest cover (defined as at least 25% tree cover from MODIS VCF data) to illustrate possible threats to the forest in Laos from potential for future deforestation. These spatial overlays present examples of how different threat for forests can be mapped with country-specific data. These examples use coarse resolution global datasets, and more detailed analysis can be done using country/province-specific data for key factors of interest.

4.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forest to other land uses depends on the amount carbon stored in the forest. Understanding where forests with high carbon stocks, and thus potential for high emissions from deforestation, are located within Laos could provide input to decisions regarding land use planning in the country.

Figure L-13 illustrates the distribution of carbon stocks across forests in Laos. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH 200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}). Table L-6 reports the percentage of forests per carbon stock category for provinces in Laos.

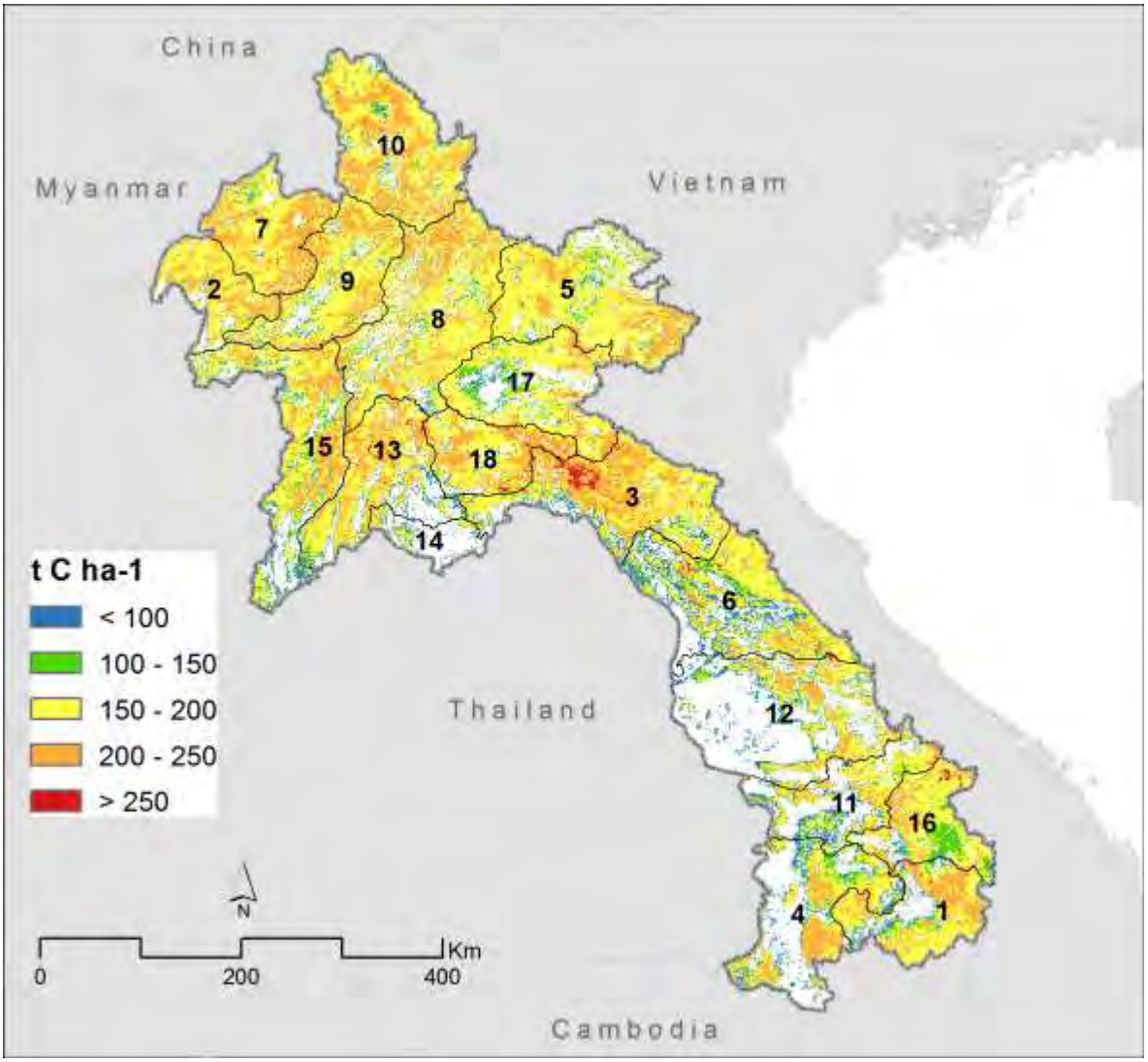


Figure L-13. Forest carbon stocks for forest cover in 2000 across Laos.

The largest percentage of forests was classified in MEDIUM HIGH carbon category (52%), followed by the HIGH carbon category (29%) and the least area of the forest was classified in VERY HIGH carbon category (1%). Forests in LOW and MEDIUM carbon category occupied the same percent of the total forests in Laos (9%).

Table L-6. Sub-national estimates as percent forest cover per carbon stock category. Carbon stocks categories are defined as LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150-200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (< 250 t C ha^{-1}).

Map ID	Provinces	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
1	Attapu	824	0	33	51	8	8
2	Bokeo	597	0	34	58	5	3
3	Bolikhamxai	1,420	4	36	47	5	7
4	Champasak	936	0	27	39	14	19
5	Houaphan	1,504	0	22	65	9	3
6	Khammouan	1,317	1	17	49	13	20
7	Louang Namtha	924	1	41	53	4	2
8	Louangphrabang	1,727	0	32	55	9	4
9	Oudomxai	1,035	0	31	56	8	4
10	Phongsali	1,416	0	39	52	6	3
11	Saravan	676	1	18	49	12	20
12	Savannakhet	967	0	22	41	14	22
13	Vientiane	976	1	34	47	8	9
14	Vientiane Prefecture	126	0	14	38	14	35
15	Xaignabouri	1,281	0	28	48	13	10
16	Xaisomboun	768	2	43	47	4	3
17	Xekong	1,016	1	18	59	17	4
18	Xiangkhoang	699	0	17	64	11	8
	Laos	**18,209**	**1**	**29**	**52**	**9**	**9**

4.3.2 Analysis #2: Forest and agriculture suitability

Most forests are cleared for agriculture (small or large scale) and soil nutrient availability is one factor that can be used to predict potential future threat to the forest. Figure L-14 illustrates the potential suitability for agriculture across the forest in 2000 based on nutrient availability in the soils. Forests with slight to moderate constraint based on soil nutrient availability were considered more suitable, while forests with severe and very severe constraints were considered not suitable for agriculture.

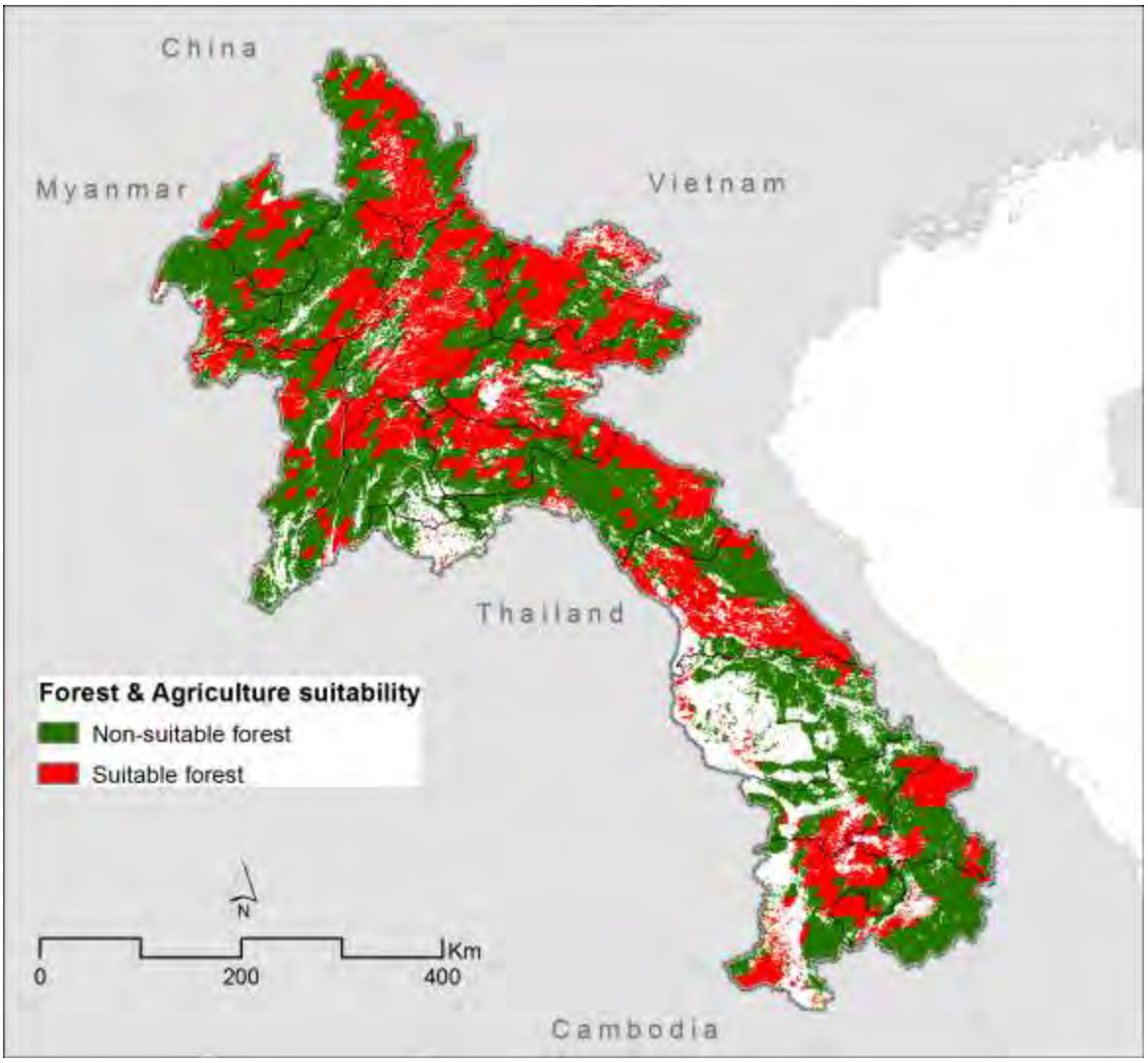


Figure L-14. Spatial overlay of forests areas in 2000 with no or slight to moderate constraints (red) and with high and very high (green) constraints on soil nutrient availability for Laos.

Figure L-15 illustrates the distribution of the carbon stock categories across forests with potential suitability for agriculture use in Laos.

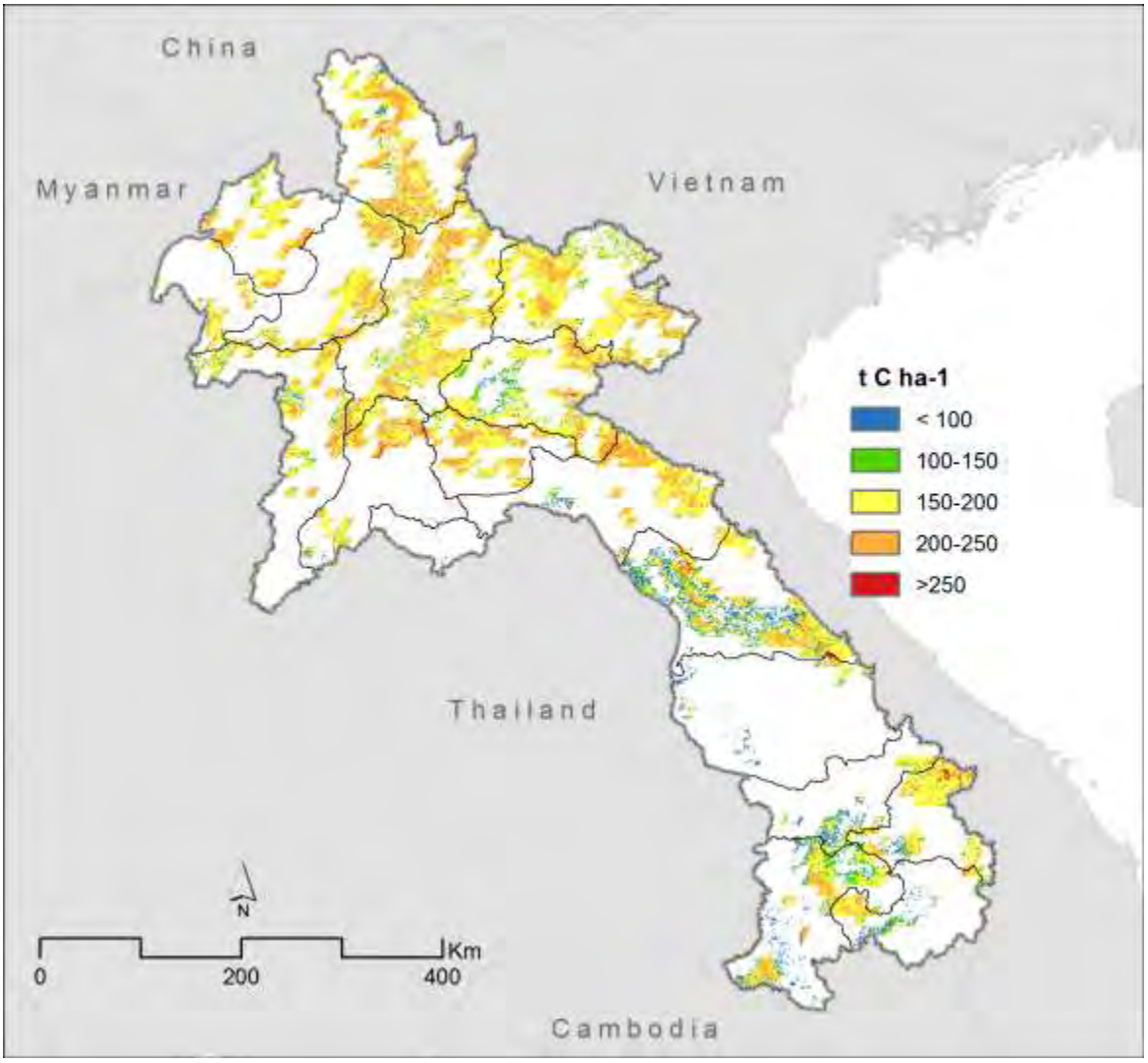


Figure L-15. Spatial overlay of forest lands suitable for agriculture and their respective forest carbon stocks.

4.3.3 Analysis #3: Forest and road network

Forests close to roads are more likely to be deforested or disturbed than forests further away from roads. Using the assumption that forest within 5km of roads is more accessible, Figure L-16 illustrates the accessibility of forests based on proximity to roads in Laos. Figure L-17 illustrates the distribution of carbon stock categories across the more accessible forest, as defined within the 5 km buffer zone around the roads.

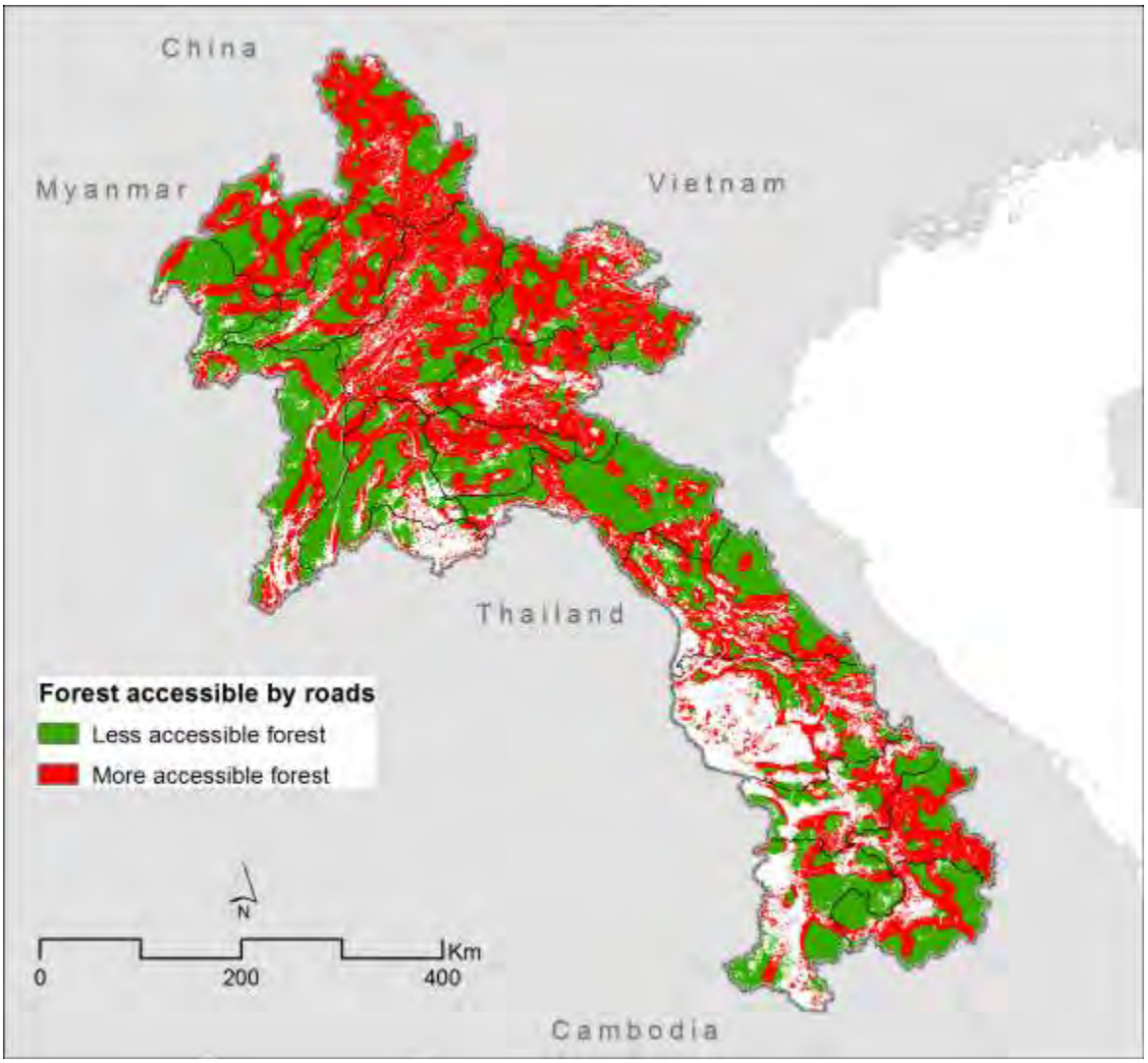


Figure L-16. Spatial overlay of forest cover in 2000 and 5 km buffer zone around road network in Laos. More accessible forests are defined as forests within 5 km buffer zone, and less accessible forests are defined as forests outside this zone.

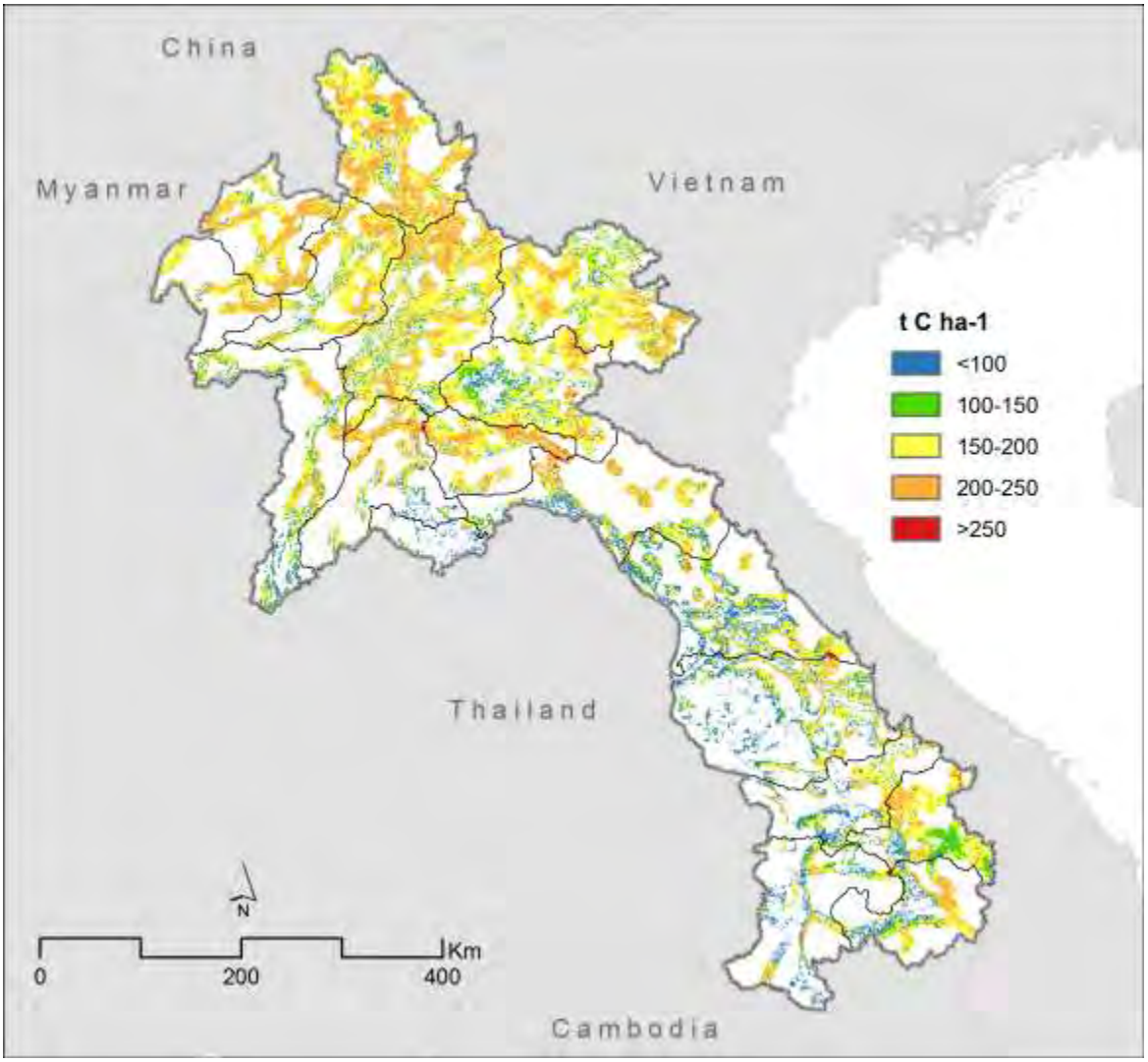


Figure L-17. Spatial overlay of more accessible forest (within 5 km buffer zone around roads) and carbon stocks.

4.3.4 Analysis #4: Forest and change in population

Increases in rural population can increase potential threat to forests as there is increased demand for land for agriculture and settlements. Figure L-18 illustrates the change in population density based on the Gridded Population of the World (GPWv3) data[4]. Most of the rural area in Laos experienced a change of population density between 20-30%. The rural area in three provinces experienced a change of population density less than 0% and only one province experienced change between 30 and 40%. If country-specific data on population are available, overlaying this more detailed dataset could indicate provinces experiencing rapid change in population density that could present a threat to their forests.

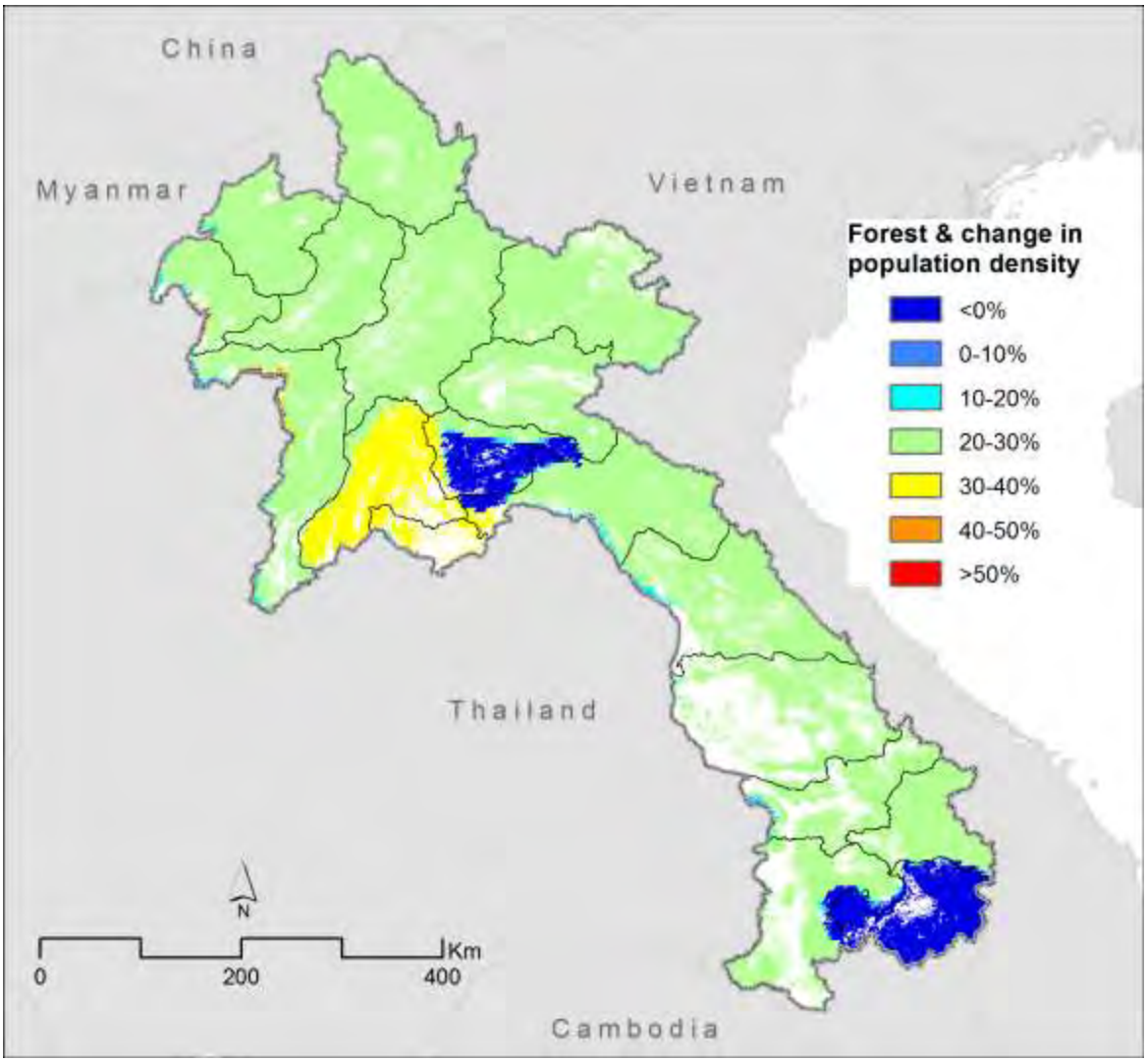


Figure L-18. Spatial overlay of forest cover and change in rural population density between 2000 and 2010.

[4] Note that this does not necessarily reflect actual population growth data based on Laos census data.

4.3.5 Analysis #5: Forest and elevation

In most cases, deforestation occurs at low elevation, where people usually live. To illustrate the potential threat to forests based on elevation, Figure L-19 shows the forest across Laos in three elevation categories: low (1-500m), medium (500-1,500m) and high (>1,500m). Most of the forests in the northern part of the country and some forests in western and southern Laos are located at medium elevation. Forests at low elevation are concentrated in the central and western part of the country, while a very small portion of the country"s forests are located at high elevation, primary in the northern part of the country.

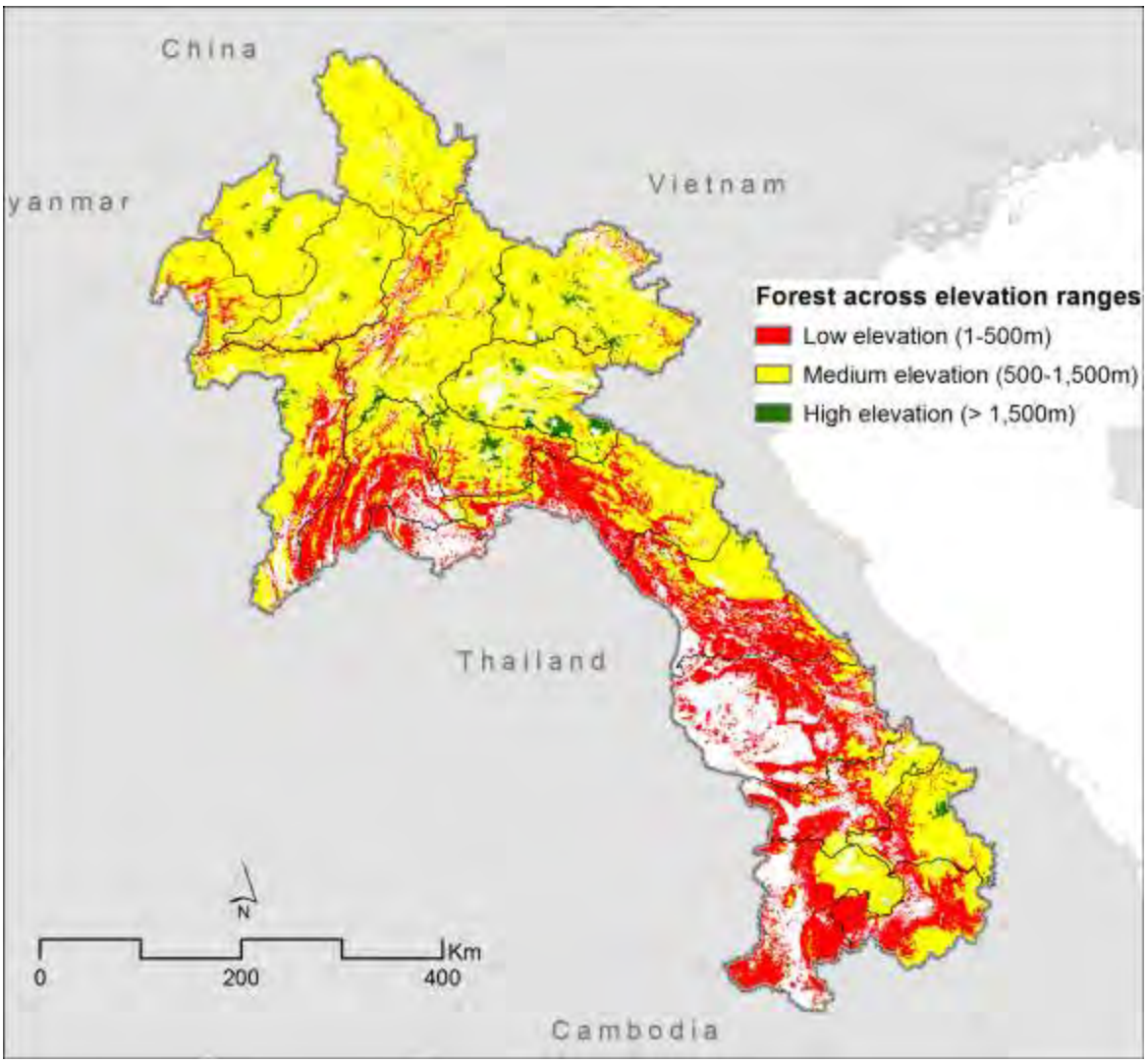


Figure L-19. Forest cover in Laos for 2000 by elevation classes.

5. MALAYSIA

This section presents the same maps and statistics given in the South and Southeast Asia Atlas (Chapter 2) reported at the subnational level for Malaysia.

5.1 NATIONAL STATISTICS RELATED TO REDD+

5.1.1 Forest cover

Figure M-1 shows the extent of forest cover in 2000 across the provinces in Malaysia, and Table M-1 reports the forest coverage per province and percent of the province area covered by forest.

Figure M-1. Forest cover in 2000 across Malaysia. Forest cover is defined greater than 25% tree cover from MODIS VCF data. Provinces are labeled according to 'Map ID' information provided in Table M-1.

According to spatial data, Sarawak province has the largest extent of forest cover (82%), while Perlis has the least extent of forest cover (19%).

Table M-1. Province-level estimates of forests and percent of province area in forest cover for 2000

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
1	Johor	1,920	968	50%
2	Kedah	956	599	63%
3	Kelantan	1,376	1,104	80%
4	Melaka	166	46	28%
5	Negeri Sembilan	670	357	53%
6	Pahang	3,601	2,847	79%
7	Perak	2,244	1,842	82%
8	Perlis	83	16	19%
9	Pulau Pinang	106	39	37%
10	Sabah	7,402	5,511	74%
11	Sarawak	12,430	10,555	85%
12	Selangor	819	468	57%
13	Trengganu	1,295	1,000	77%
	Malaysia	**33,069**	**25,353**	**77%**

5.1.2 Forest Cover in Protected Areas

Figure M-2 illustrates the area of Malaysia forest in protected areas, and Table M-2 reports the actual forest area and percent forest in protected area per province.

Figure M-2. Distribution of forest cover in 2000 within protected area across Malaysia. Provinces are labeled according to 'Map ID' information provided in Table M-2.

The province with the highest percent forest in protected areas is Kedah (27%), with 416,000 ha protected forest. The province with the least percent forest in protected area is Negeri Sembilan (1%), with 3,000 ha protected forest. Melaka province has no forest in protected areas. Sarawak province has the highest area of forest in its protected areas (942,000 ha), but it accounts for only 9% of total forest in the province.

Table M-2. Province-level estimates of forests in protected areas and percent protected forests of the total forest area in Malaysia

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
1	Johor	192	20%
2	Kedah	159	27%
3	Kelantan	121	11%
4	Melaka*	-	-
5	Negeri Sembilan	3	1%
6	Pahang	460	16%
7	Perak	288	16%
8	Perlis	1	6%
9	Pulau Pinang	1	2%
10	Sabah	708	13%
11	Sarawak	942	9%
12	Selangor	16	3%
13	Trengganu	127	13%
	Malaysia	**3,018**	**12%**

** No forest cover and percent forest cover in protected areas for this province*

5.1.3 Gross Forest Cover Loss

The annual gross forest cover loss between 2000 and 2005 is shown in Figure M-3, with a summary of the actual values presented in Table M-3.

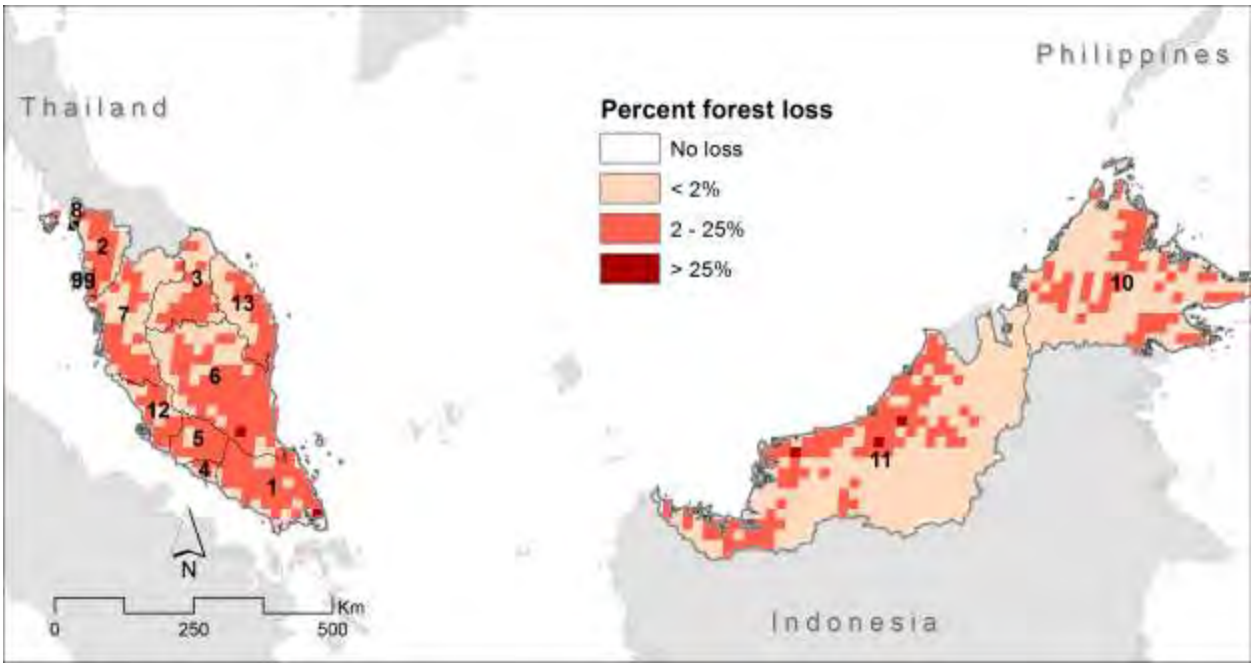


Figure M-3. Distribution of gross forest cover loss between 2000 and 2005 across Malaysia. Provinces are labeled according to 'Map ID' information provided in Table M-3.

Melaka province had the highest gross forest loss (4.9%), while Perlis had the lowest gross forest loss (0.3%) expressed as a percent of the initial forests in 2000

Table M-3. Province-level estimates of average annual gross forest cover loss between 2000 and 2005 expressed as hectares and percent of the forest cover in 2000

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
1	Johor	21,863	2.3%
2	Kedah	8,341	1.4%
3	Kelantan	10,663	1.0%
4	Melaka	2,286	4.9%
5	Negeri Sembilan	10,353	2.9%
6	Pahang	43,281	1.5%
7	Perak	14,281	0.8%
8	Perlis	55	0.3%
9	Pulau Pinang	531	1.4%
10	Sabah	33,344	0.6%
11	Sarawak	69,080	0.7%
12	Selangor	7,719	1.6%
13	Trengganu	9,191	0.9%
	Malaysia	**230,988**	**1.1%**

5.1.4 Biomass Carbon Stocks

Figure M-4 illustrates the distribution of the biomass carbon stocks according to Saatchi et al. (2011) clipped to the boundary of Malaysia.

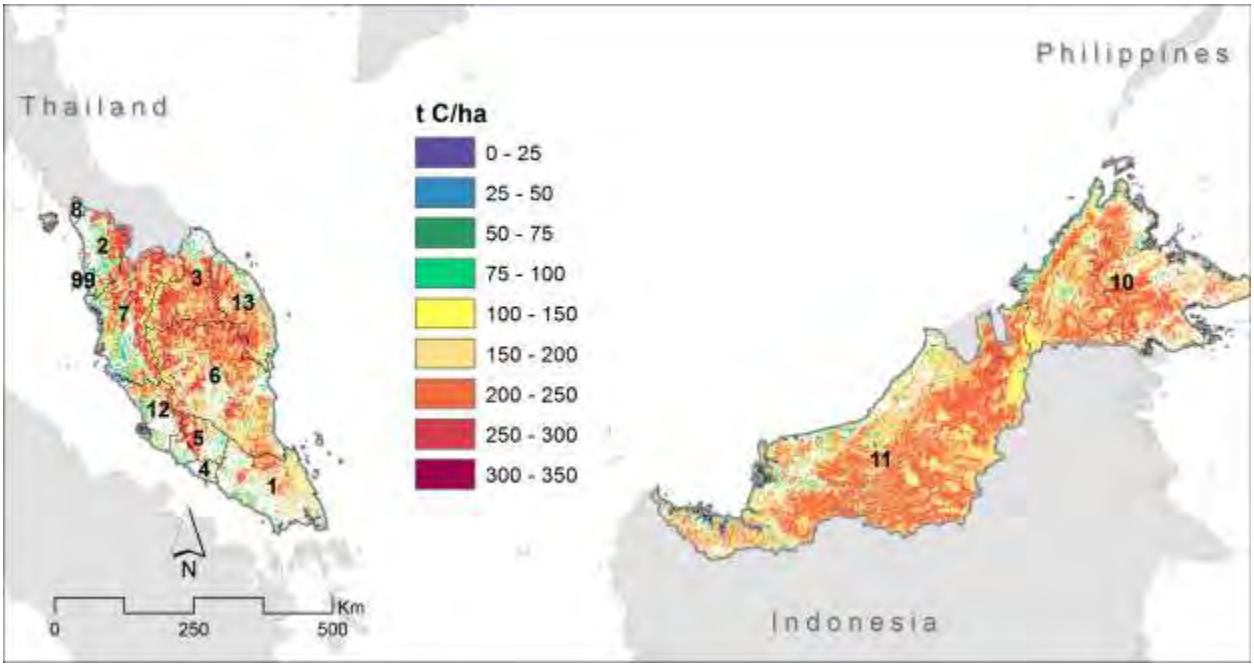


Figure M-4. Distribution of above and belowground forest biomass carbon stocks across Malaysia. Provinces are labeled according to 'Map ID' information provided in Table M-4.

The forests in Kelantan province were with highest area weighted carbon stocks (199 t C ha-1), while forests in Pulau Pinang were with the lowest area weighted carbon stocks (98 t C ha-1). The total forest carbon stock for the forest in 2000 was estimated at 4,680 Million t C, with Sarawak contributing the most with 1,974 Million t C, and Perlis contributing the least to the total forest carbon stocks with 2 Million t C

Table M-4. Province-level estimates of above and belowground forest biomass carbon expressed as area weighted average (t C ha^{-1}) and total carbon (t C)

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Million t C)
1	Johor	158	153
2	Kedah	175	105
3	Kelantan	199	220
4	Melaka	114	5
5	Negeri Sembilan	181	65
6	Pahang	194	553
7	Perak	185	341
8	Perlis	139	2
9	Pulau Pinang	98	4
10	Sabah	181	998
11	Sarawak	187	1,974
12	Selangor	158	74
13	Trengganu	187	188
	Malaysia	**166**	**4,680**

5.1.5 Carbon emissions from deforestation

Annual carbon emissions from deforestation between 2000 and 2005 for Malaysia are shown in Figure M-5.

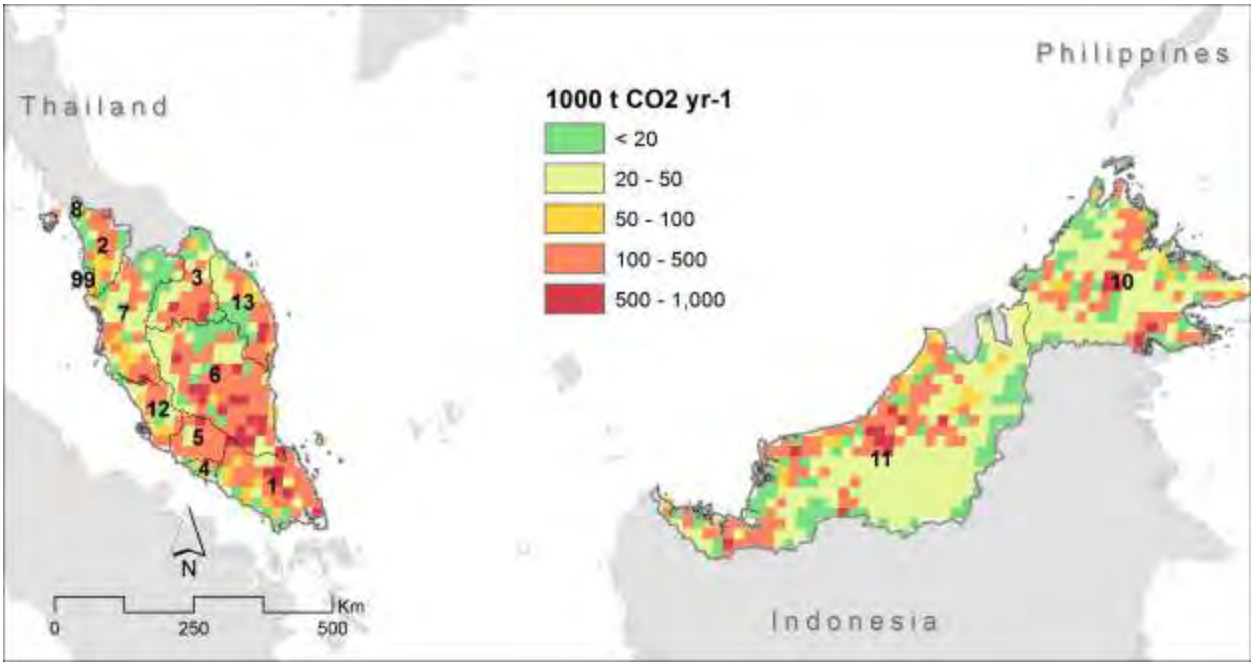


Figure M-5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005 for Malaysia. Provinces are labeled according to 'Map ID' information provided in Table M-5.

Table M-5 reports the annual emissions from deforestation per province. Sarawak province was found to have the highest annual CO_2 emissions from deforestation (35,469,000 t CO_2 yr^{-1}), followed by Pahang province with 25,654,000 t CO_2 yr^{-1}. Perlis and Pulau Pinang province were found to have the lowest annual CO_2 emissions of deforestation between 2000 and 2005, 26 thousand t CO_2 yr^{-1} and 142,000 t CO_2 yr^{-1}, respectively.

Table M-5. Province level estimates of carbon emissions (t CO_2 yr^{-1}) from deforestation between 2000 and 2005

Map ID	Province	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
1	Johor	10,512
2	Kedah	3,510
3	Kelantan	6,936
4	Melaka	726
5	Negeri Sembilan	4,554
6	Pahang	25,654
7	Perak	6,525
8	Perlis	26
9	Pulau Pinang	142
10	Sabah	18,622
11	Sarawak	35,469
12	Selangor	2,686
13	Trengganu	4,843
	Malaysia	**120,206**

5.2 FACTORS FOR NATIONAL CIRCUMSTANCES

This section illustrates the factors that are often used to explain patterns of deforestation across Malaysia. All factors are subsets from the regional factors presented in the regional Atlas (section 3.2). Maps of elevation, roads, settlements (populated places), climate zones, soil nutrient availability, protected areas and rural population growth are shown in Figures M-6-12.

5.2.1 Elevation

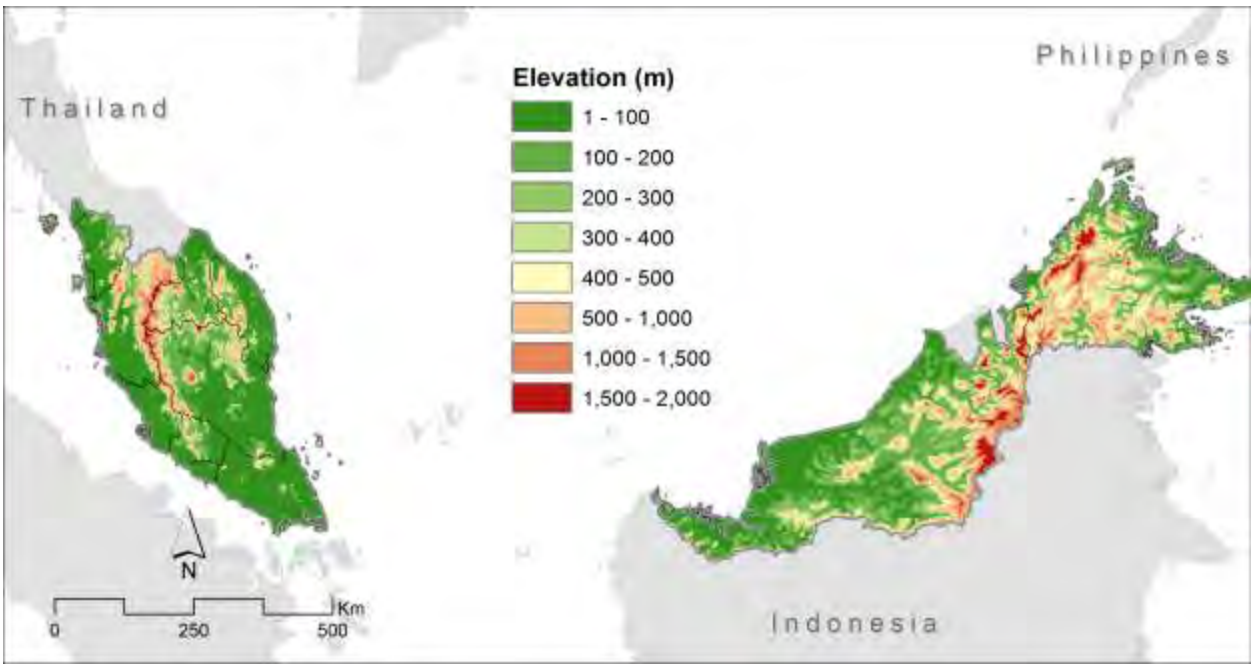


Figure M-6. Elevation across Malaysia.

5.2.2 Roads

Figure M-7. Location of roads across Malaysia.

5.2.3 Settlements

Figure M-8. Map of all settlements (populated places) across Malaysia.

5.2.4 Climate

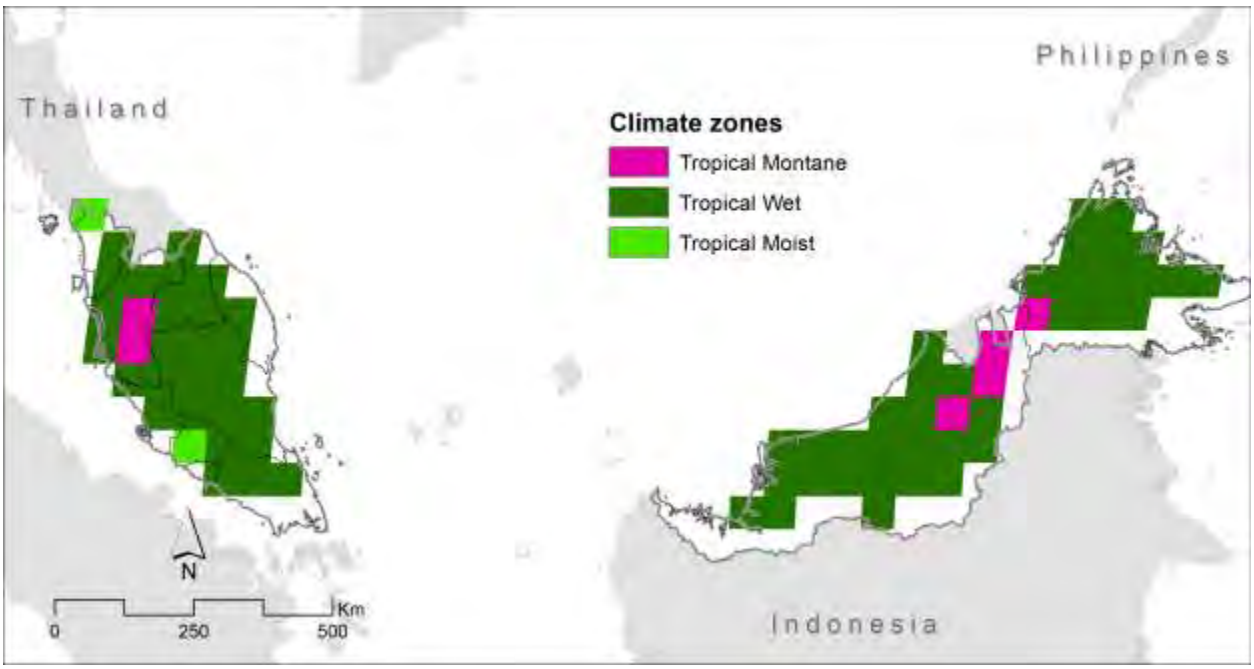


Figure M-9. Map of Climate zones across Malaysia.

5.2.5 Soil nutrient availability

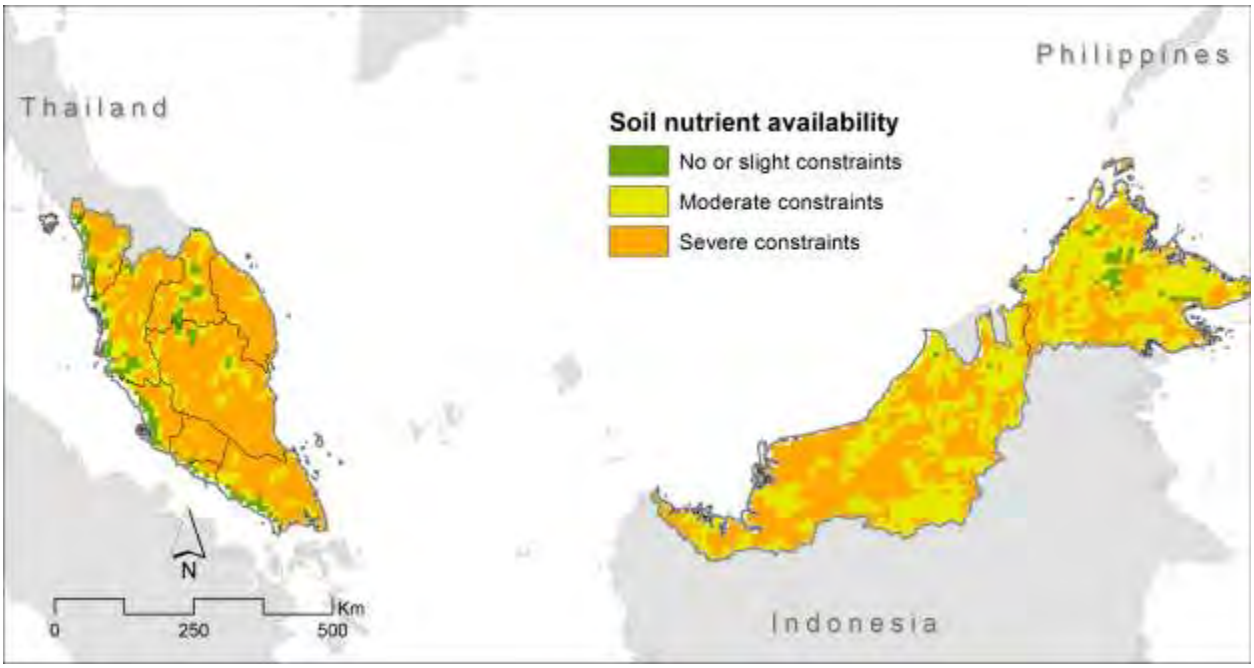


Figure M-10. Map of soil nutrient availability across Malaysia.

5.2.6 Rural population growth

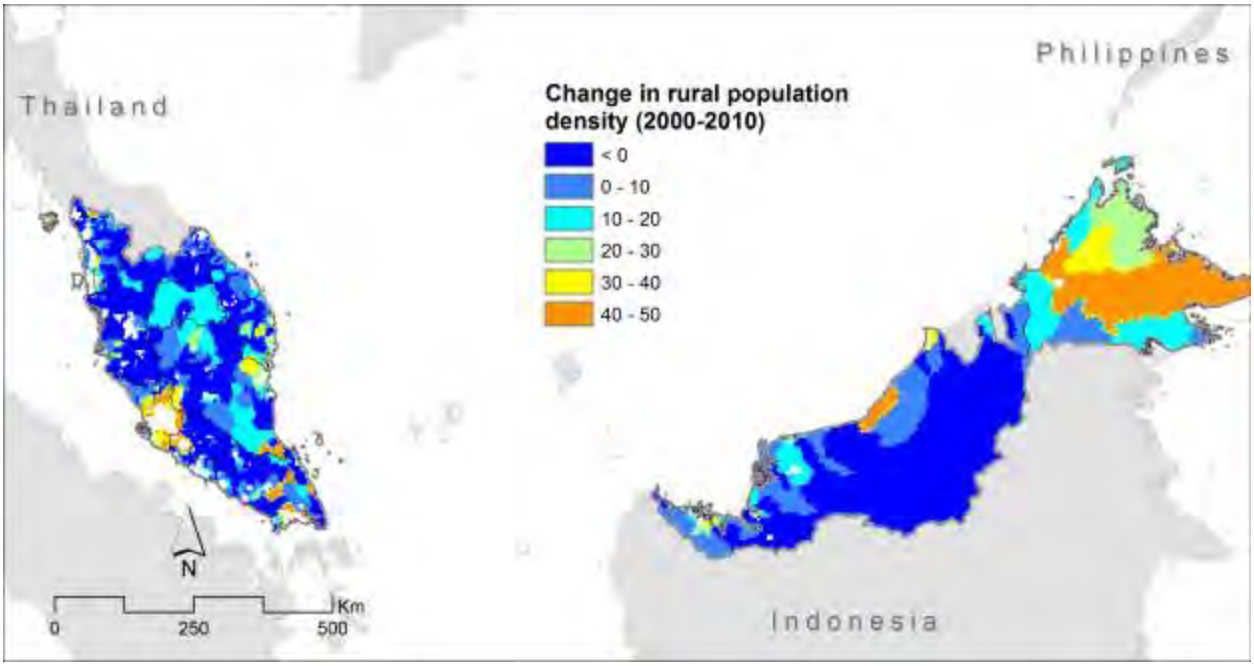


Figure M-11. Rural population growth shown as percent population density.

5.2.7 Protected areas

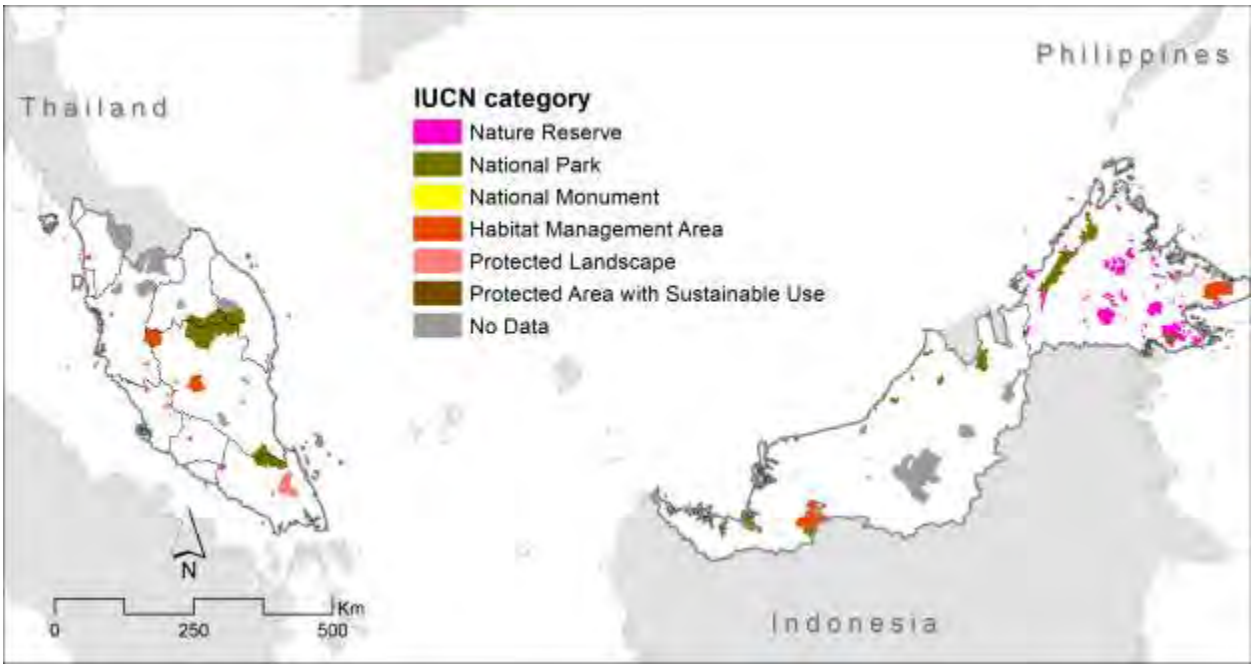


Figure M-12. Map of Protected Areas by IUCN category.

5.3 FOREST THREATS

This section presents spatial overlays of different factors over the 2000 map of forest cover (defined as at least 25% tree cover from MODIS VCF data) to illustrate possible threats to the forest in Malaysia in terms of potential for future deforestation. These spatial overlays present several examples of how different threat for forests can be mapped with country-specific data. These examples use coarse resolution global datasets, and more detailed analysis can be done using country/province-specific data for key factors of interest.

5.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forest to other land uses depends on the amount carbon stored in the forest. Understanding where forests with high carbon stocks, and thus potential for high emissions from deforestation, are located within Malaysia could provide input to decisions regarding land use planning in the country.

Figure M-13 illustrates the distribution of carbon stocks categories across forests in Malaysia. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH 200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}).

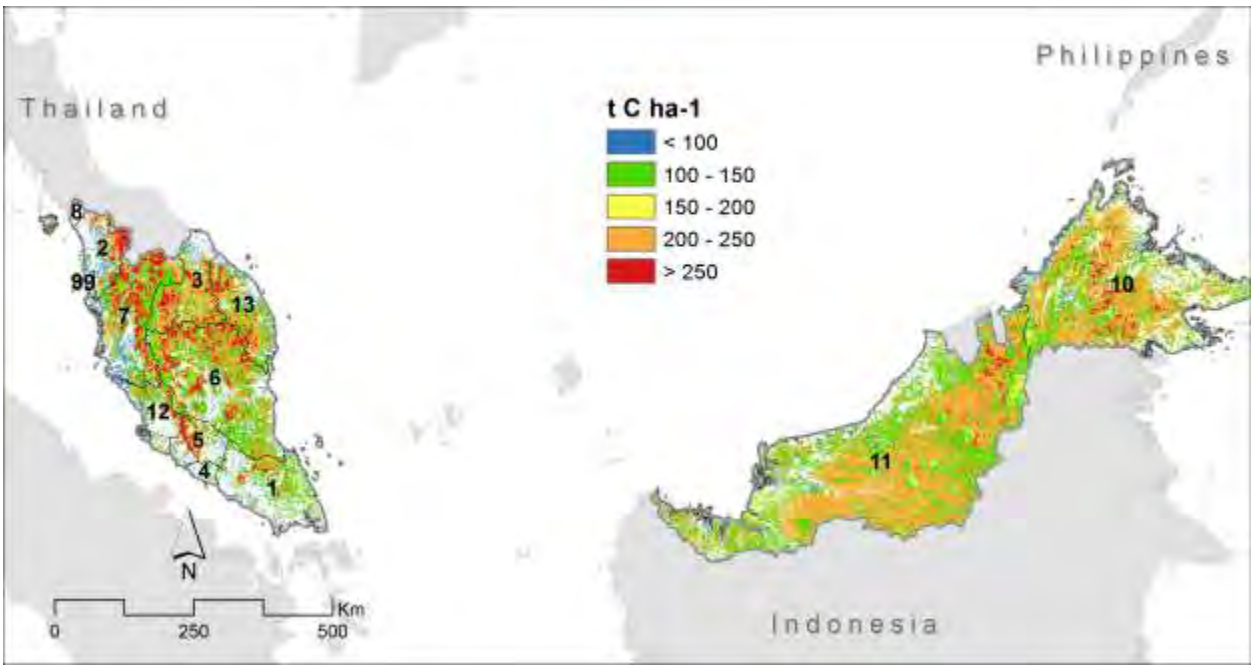


Figure M-13. Forest carbon stocks for forest cover in 2000 across Malaysia.

Table M-6 reports the percent forests per carbon stock category for provinces in Malaysia. The largest part of the forests was classified in HIGH carbon category (38%), followed by the MEDIUM carbon category (35%) and the least area of the forest was classified in VERY HIGH carbon category (8%). Forests in LOW carbon category occupied 10% the total forests in Malaysia.

Table M-6. Sub-national estimates as percent forest cover per carbon stock category. Carbon stocks categories are defined as LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150-200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (< 250 t C ha^{-1})

Map ID	Provinces	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock	Percent forest with HIGH carbon stock	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
1	Johor	968	6	14	16	42	22
2	Kedah	599	24	23	12	14	27
3	Kelantan	1,104	17	42	6	29	6
4	Melaka	46	0	4	23	21	51
5	Negeri Sembilan	357	20	25	12	23	20
6	Pahang	2,847	16	29	7	43	6
7	Perak	1,842	23	20	10	31	16
8	Perlis	16	0	38	16	16	29
9	Pulau Pinang	39	0	5	20	14	61
10	Sabah	5,511	6	40	12	32	10
11	Sarawak	10,555	2	47	9	36	6
12	Selangor	468	11	20	17	26	27
13	Trengganu	1,000	14	34	7	33	11
	Malaysia	**25,353**	**8**	**38**	**10**	**35**	**10**

5.3.2 Analysis #2: Forest and agriculture suitability

Most forests are cleared for agriculture (small or large scale), and soil nutrient availability is one factor that can predict potential future threat to the forest. Figure M-14 illustrates the potential suitability for agriculture across the forest in 2000 based on nutrient availability in the soils. Forests with slight to moderate constraints based on soil nutrient availability were considered more suitable, while forests with severe and very severe constraints were considered not suitable for agriculture. Figure M-15 illustrates the distribution of the carbon stock categories across forests with potential suitability for agriculture use in Malaysia.

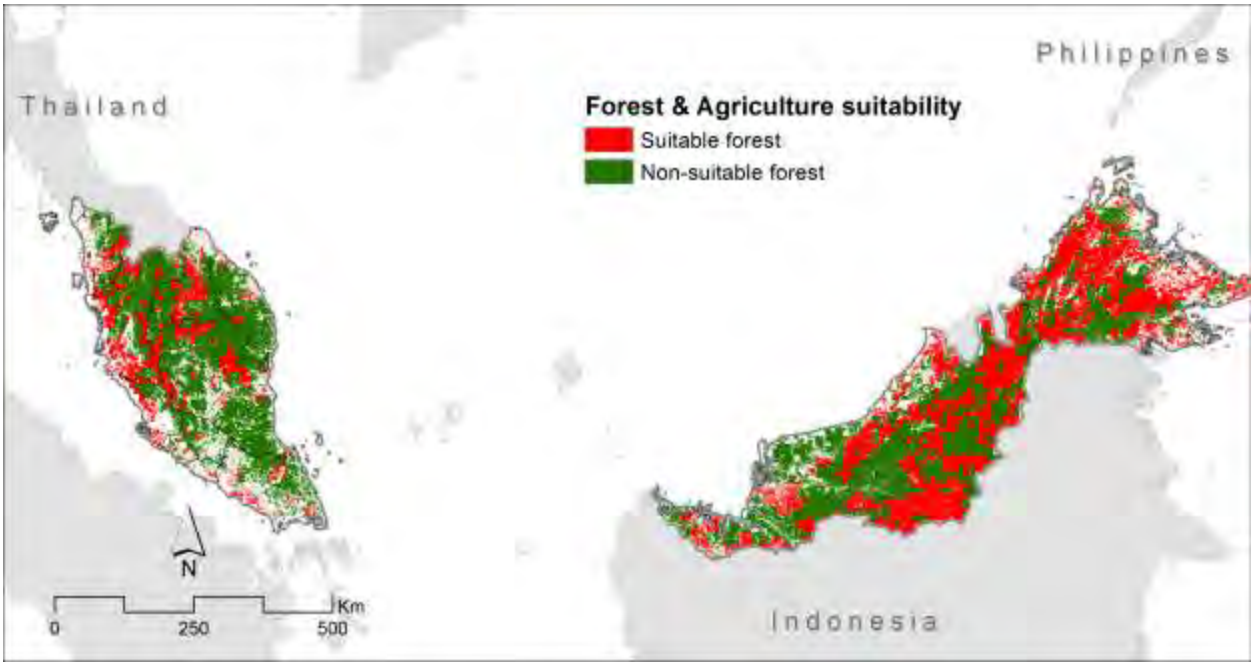


Figure M-14. Spatial overlay of forests areas in 2000 with no or slight to moderate constraint (red) and with high and very high (green) constrains on soil nutrient availability for Malaysia.

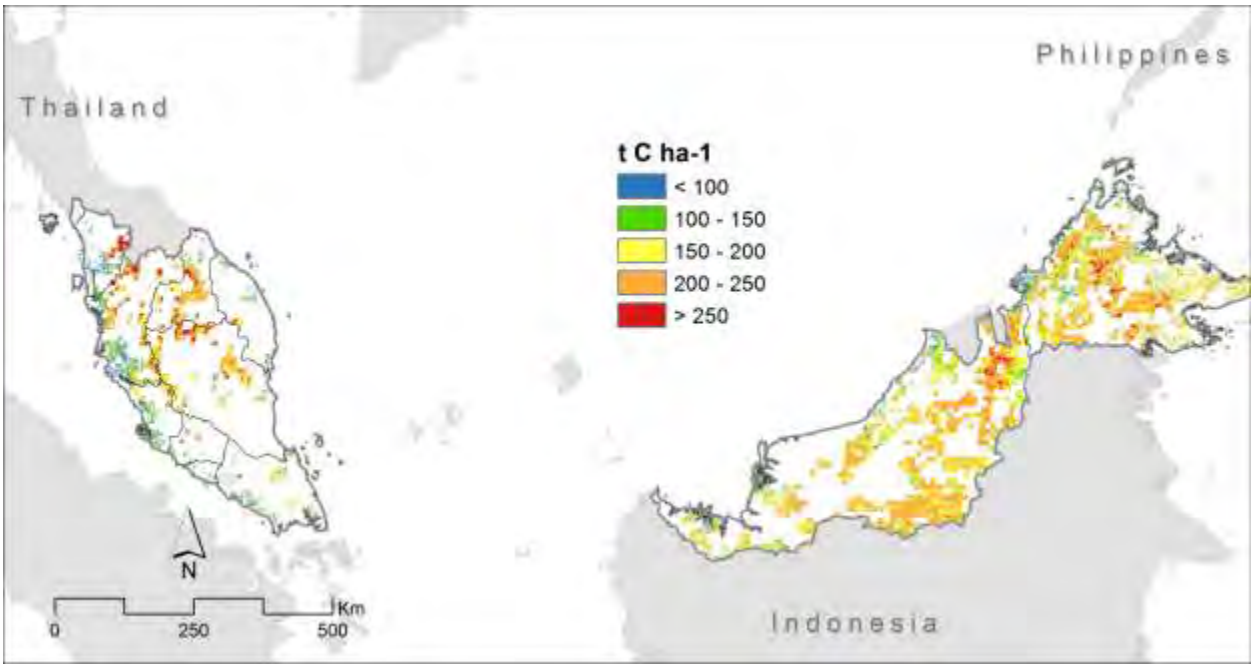


Figure M-15. Spatial overlay of forest lands suitable for agriculture and their respective forest carbon stocks.

5.3.3 Analysis #3: Forest and road network

Forests close to roads are more likely to be deforested or disturbed than forests further away from roads. Using the assumption that forests within 5km of roads are more accessible, Figure M-16 illustrates the accessibility of forest areas in Malaysia. Figure M-17 illustrates the distribution of carbon stock categories across the more accessible forest, defined within the 5 km buffer zone around the roads.

Figure M-16. Spatial overlay of forest cover in 2000 and 5 km buffer zone around road network in Malaysia. More accessible forests are defined as forests within 5 km buffer zone and less accessible forests are defined as forests outside this zone.

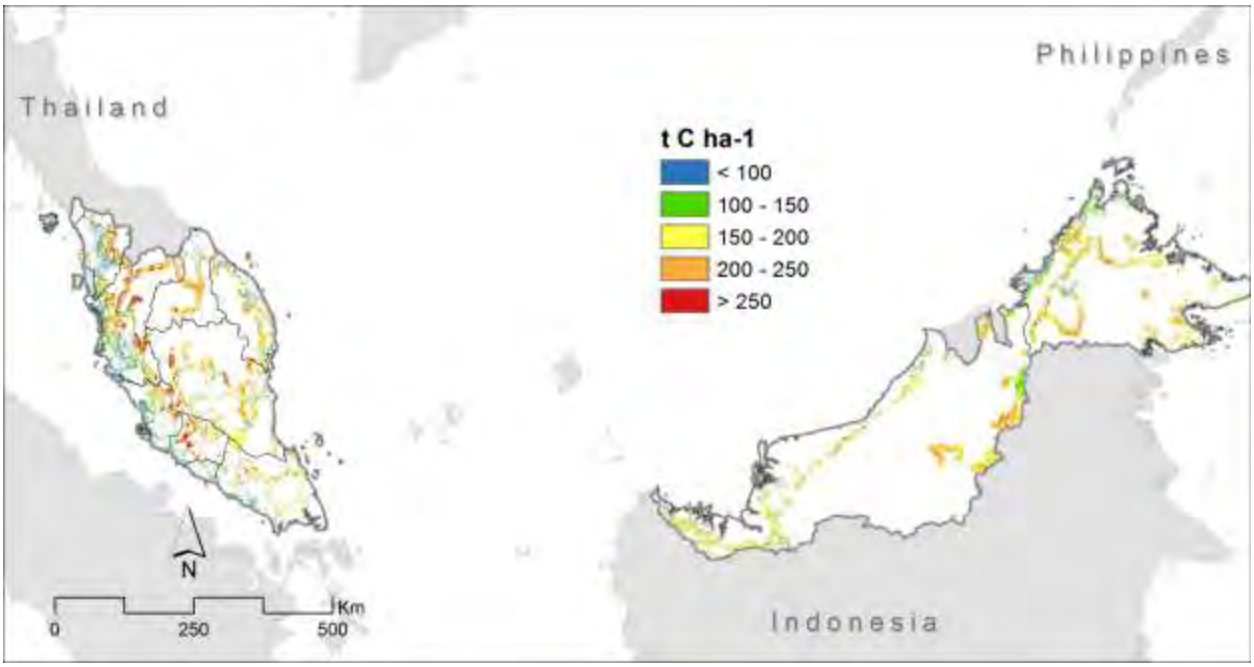


Figure M-17. Spatial overlay of more accessible forest (within 5 km buffer zone around roads) and carbon stocks.

5.3.4 Analysis #4: Forest and change in population

Increases in rural population can result in a corresponding increase in potential threat to forests. Figure M-18 illustrates the change in population density based on the Gridded Population of the World (GPWv3) data[5]. The rural area in Peninsular Malaysia experienced a change of population density less than 20%, while the change of population density in Malaysian Borneo ranges from low (less than 10%) for the south provinces to high (40-50%) for the north provinces. Although the GPWv3 data for Malaysia are at province level for 2000 and projected for 2010, if national census data exist for 2010, more detailed actual change of population density could be estimated to present a clearer picture of the threat to Malaysian forests.

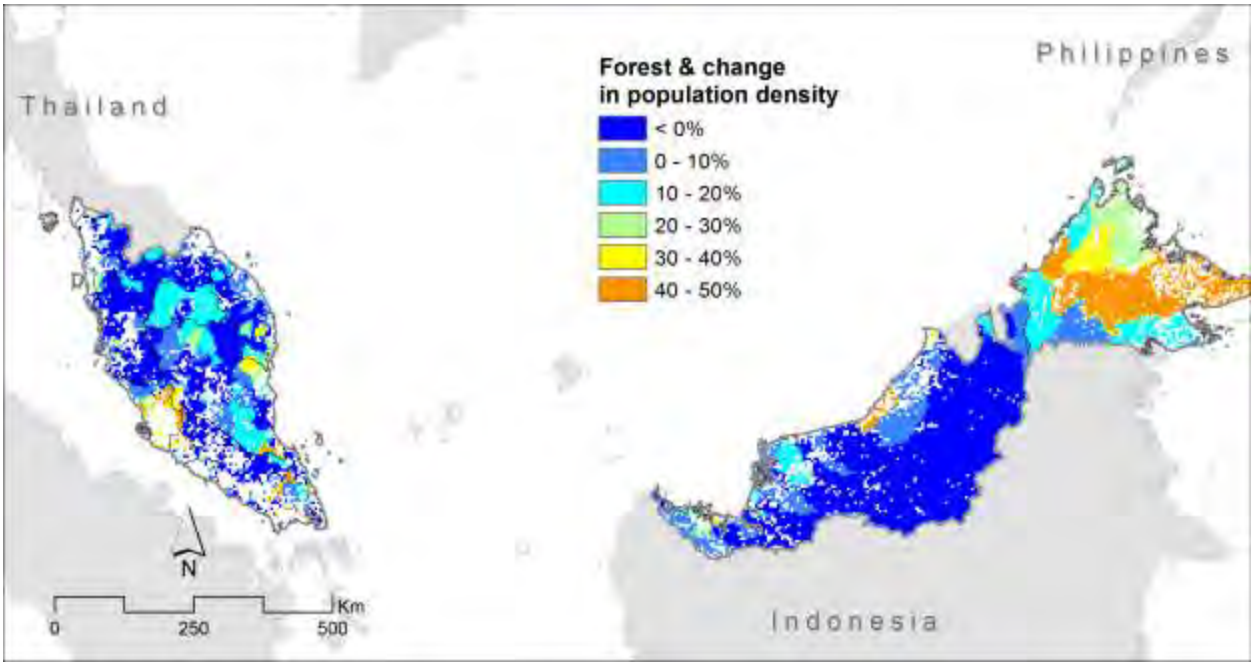


Figure M-18. Spatial overlay of forest cover and change in rural population density between 2000 and 2010

[5] Note that these data do not necessarily reflect actual population growth based on Malaysia census data.

5.3.5 Analysis #5: Forest and elevation

In most cases deforestation occurs at low elevations, where people usually live. To illustrate the potential threat to forests based on elevation, Figure M-19 shows the forest across Malaysia in three elevation categories: low (1-500m), medium (500-1,500m) and high (>1,500m). Most of the forests in Malaysia are located at low elevation, presenting real threat of deforestation if combined with other factors. Some forests are located at medium and high elevation, primarily in Malaysian Borneo.

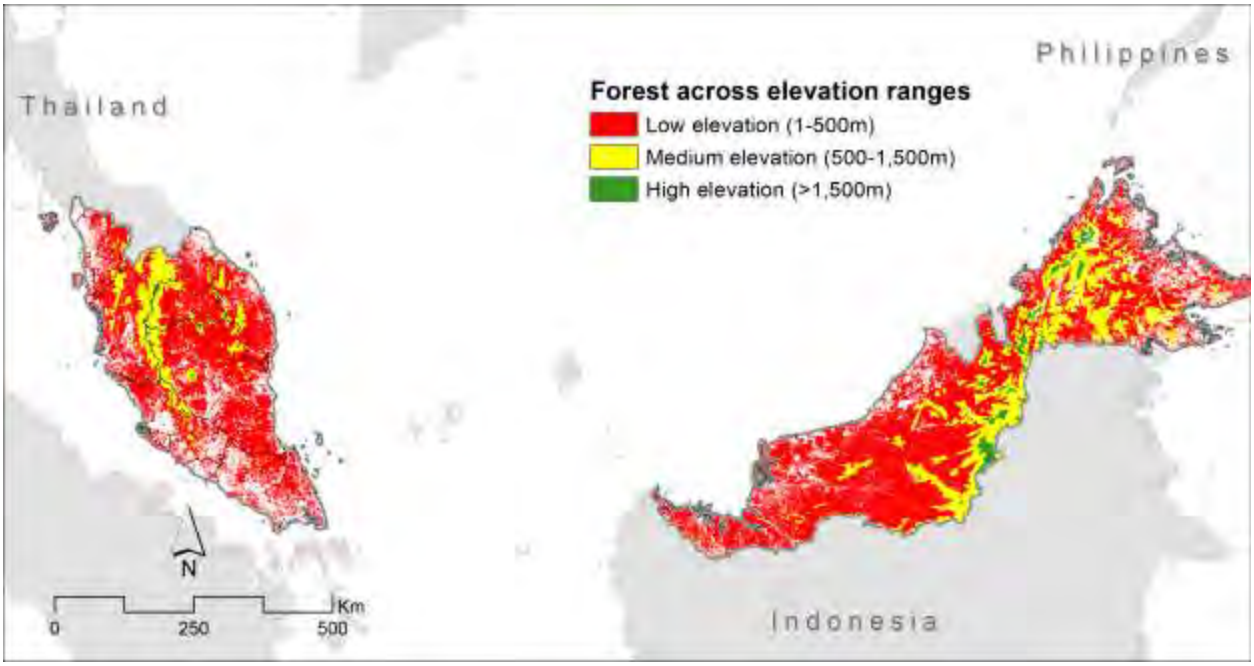


Figure M-19. Forest cover in Malaysia for 2000 by elevation classes

6. PAPUA NEW GUINEA

This section presents the same maps and statistics given in the South and Southeast Asia Atlas (Chapter 2) reported at the subnational level for Papua New Guinea (PNG). These highlight key factors that should be considered for defining national circumstances, and illustrate forest threats based on roads, change in population density, elevation and suitability for agriculture based on nutrient availability.

6.1 NATIONAL STATISTICS RELATED TO REDD+

6.1.1 Forest cover

Figure P-1 shows the extent of forest cover in 2000 across the provinces in Papua New Guinea, and Table P-1 reports the forest coverage per province and percent of the province area covered by forest.

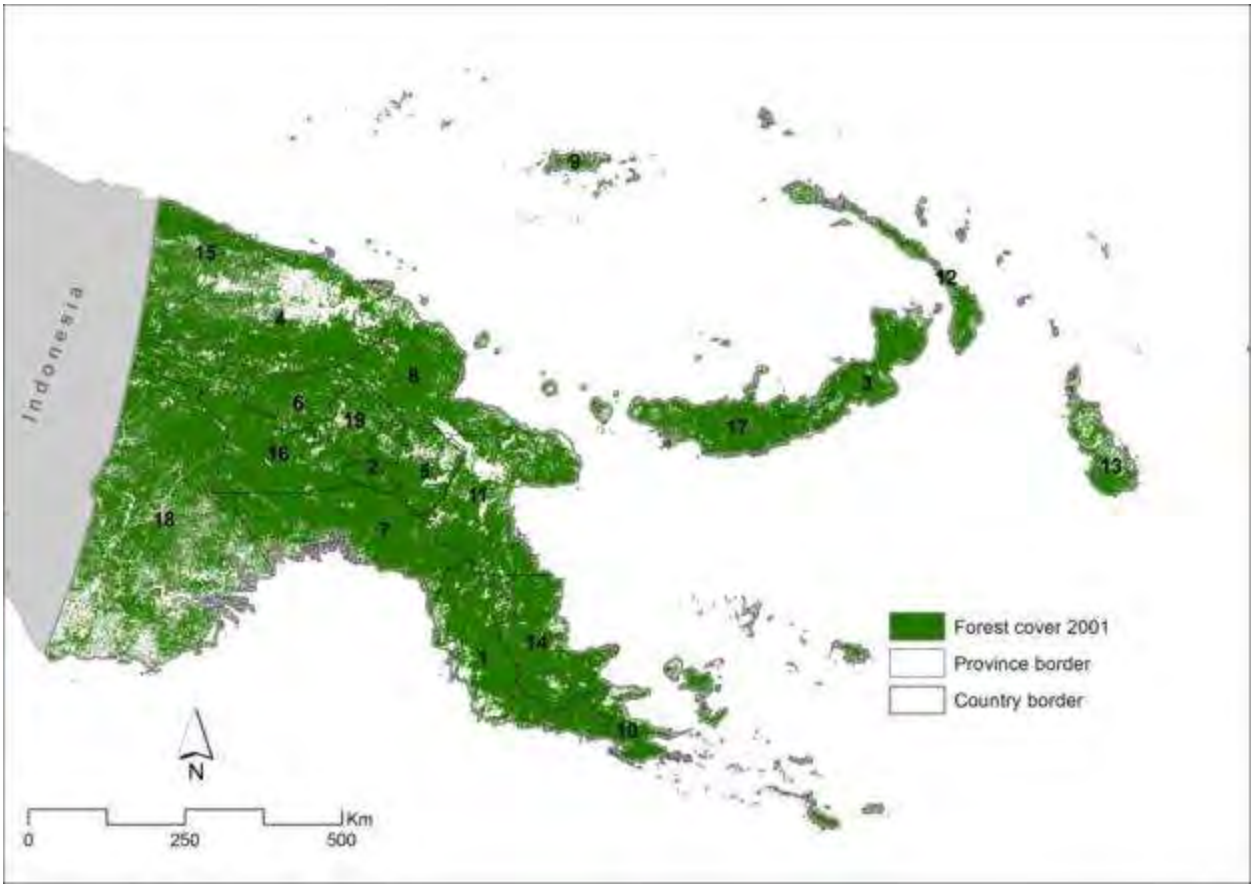


Figure P-1. Forest cover in 2000 across Papua New Guinea. Forest cover is defined greater than 25% tree cover from MODIS VCF data. Provinces are labeled according to 'Map ID' information provided in Table P-1.

According to spatial data, 81% of the total area is forested. Enga province has the largest extent of forest cover (93%), while East Sepik, Manus and Western province have the least extent of forest cover (70%).

Table P-1. Province-level estimates of forests and percent of province area in forest cover for 2000[6]

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
1	Central	2,983	2,612	88%
2	Chimbu	617	565	92%
3	East New Britain	1,542	1,401	91%
4	East Sepik	4,385	3,078	70%
5	Eastern Highland	1,119	880	79%
6	Enga	1,179	1,101	93%
7	Gulf	3,495	3,158	90%
8	Madang	2,907	2,505	86%
9	Manus	225	158	70%
10	Milne Bay	1,443	1,183	82%
11	Morobe	3,411	2,675	78%
12	New Ireland	972	808	83%
13	North Solomons	945	711	75%
14	Northern	2,280	2,082	91%
15	Sandaun	3,585	2,928	82%
16	Southern Highland	2,582	2,419	94%
17	West New Britain	2,047	1,862	91%
18	Western	9,948	6,951	70%
19	Western Highland	916	781	85%
	Papua New Guinea	**46,582**	**37,856**	**81%**

[6] The PNG forest cover area in this table may differ slightly from the figures reported under Section 2.1.1, Table 1 due to differences in data and methods for calculating forest area at regional and national /subnational scales.

6.1.2 Forest Cover in Protected Areas

Figure P-2 illustrates the forest area in Papua New Guinea"s protected areas, and Table P-2 reports the actual forest area and percent forest in protected area per province. Only 2% of total forests in Papua New Guinea are under protection.

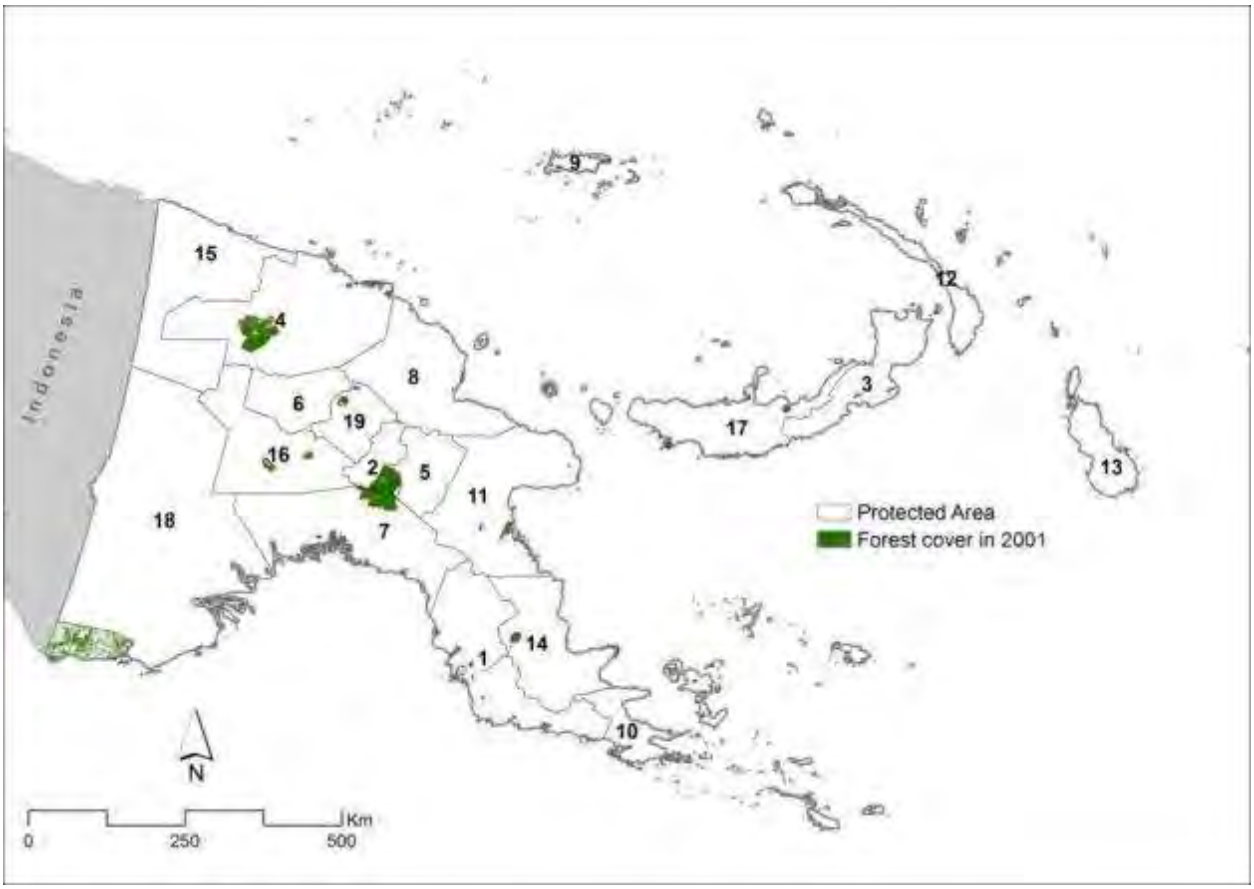


Figure P-2. Distribution of forest cover in 2000 within protected area across Papua New Guinea. Provinces are labeled according to 'Map ID' information provided in Table P-2.

The province with the highest percent forest in protected area is Chimbu (16%), with 89,000 ha protected forests. The province with the least percent forest in protected area is North Solomons (0%), with 1,000 ha protected forests. Enga, Munus and Sandaum province do not have any of their forests under protection.

Table P-2. Province-level estimates of forests in protected areas and percent protected forests of the total forest area in Papua New Guinea

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
1	Central	12	0%
2	Chimbu	89	16%
3	East New Britain	6	0%
4	East Sepik	211	7%
5	Eastern Highland	53	6%
6	Enga	0	0%
7	Gulf	130	4%
8	Madang	39	2%
9	Manus	0	0%
10	Milne Bay	16	1%
11	Morobe	27	1%
12	New Ireland	14	2%
13	North Solomons	1	0%
14	Northern	19	1%
15	Sandaun	0	0%
16	Southern Highlands	30	1%
17	West New Britain	18	1%
18	Western	257	4%
19	Western Highland	19	2%
	Papua New Guinea	**540**	**2%**

6.1.3 Gross Forest Cover Loss

The annual gross forest cover loss between 2000 and 2005 in Papua New Guinea is shown in Figure P-3, with a summary of the actual values presented in Table P-3.

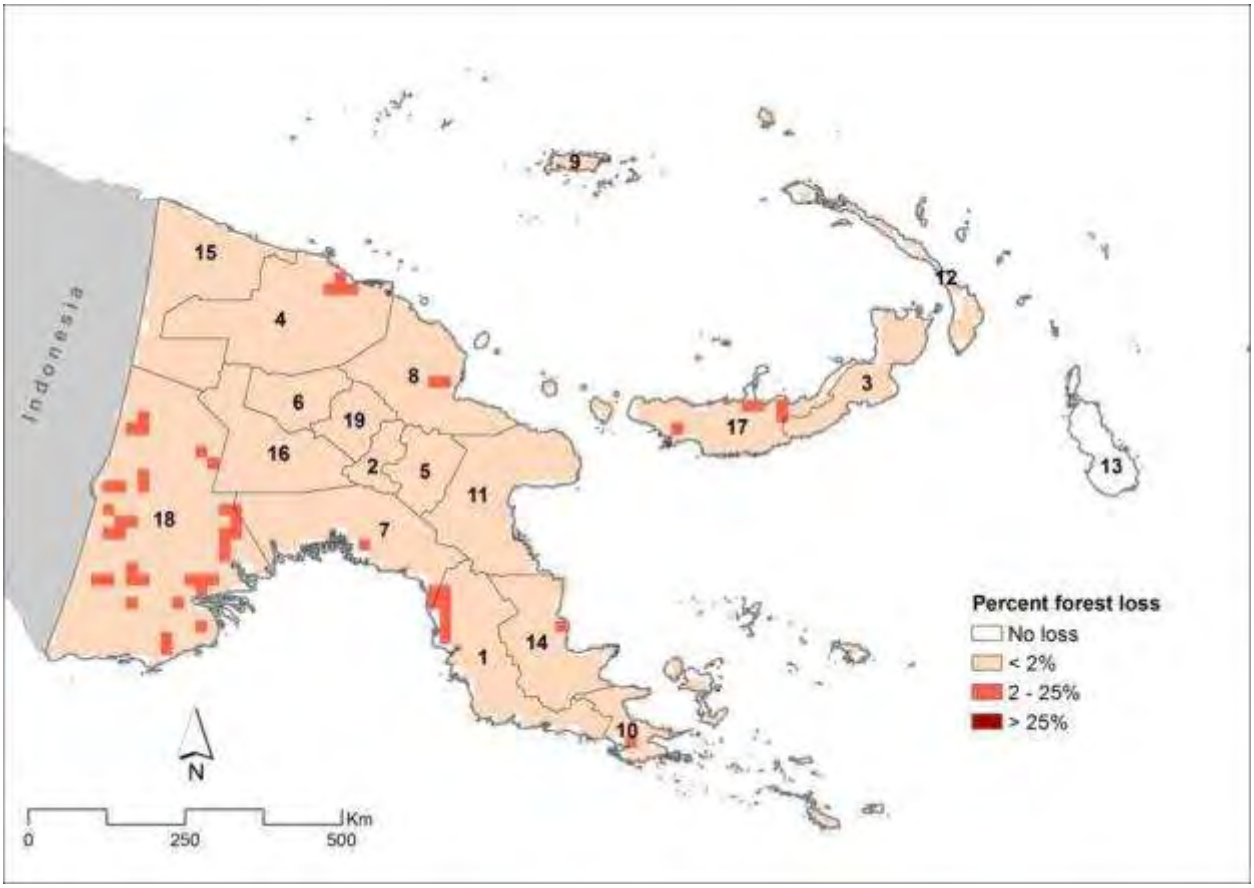


Figure P-3. Distribution of gross forest cover loss between 2000 and 2005 across Papua New Guinea. Provinces are labeled according to 'Map ID' information provided in Table P-3.

West New Britain, with 0.23% loss of forest cover, is the province with highest gross forest loss expressed as a percent of the forests in 2000. East New Britain and Southern Highlands, with 0.07% loss, are the provinces with lowest gross forest loss expressed as percent of the forest cover in 2000.

Table P-3. Province-level estimates of average annual gross forest cover loss between 2000 and 2005 expressed as hectares and percent of the forest cover in 2000

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
1	Central	2,933	0.11%
2	Chimbu	638	0.11%
3	East New Britain	915	0.07%
4	East Sepik	4,021	0.13%
5	Eastern Highlands	1,218	0.14%
6	Enga	1,127	0.10%
7	Gulf	2,329	0.07%
8	Madang	3,845	0.15%
9	Manus	205	0.13%
10	Milne Bay	1,506	0.13%
11	Morobe	3,405	0.13%
12	New Ireland	950	0.12%
13	North Solomons*	-	-
14	Northern	1,122	0.05%
15	Sandaun	2,858	0.10%
16	Southern Highlands	1,715	0.07%
17	West New Britain	4,281	0.23%
18	Western	14,611	0.21%
19	Western Highlands	910	0.12%
	Papua New Guinea	**48,590**	**0.13%**

** No average annual gross loss in forest area and percent of the forest cover in 2000 for this province*

6.1.4 Biomass Carbon Stocks

Figure P-4 illustrates the distribution of the biomass carbon stocks according to Saatchi et al. (2011) clipped to the boundary of Papua New Guinea.

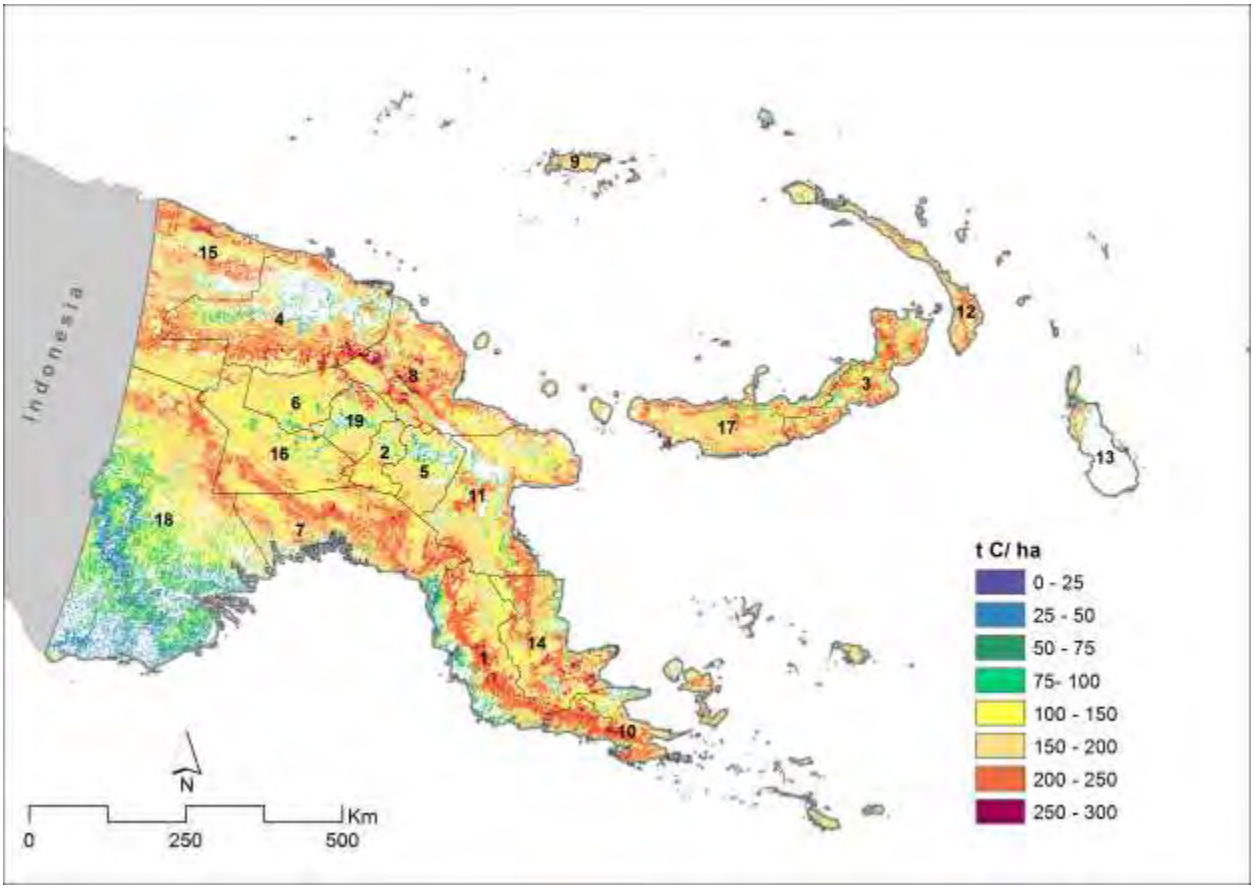


Figure P-4. Distribution of above and belowground forest biomass carbon stocks across Papua New Guinea for the forest in 2000. Provinces are labeled according to 'Map ID' information provided in Table P-4.

The area weighted forest carbon in Madang province was the highest with estimate of 180 t C ha^{-1}, while in Western the area weighted forest carbon was the lowest with estimated of 115 t C ha^{-1}. The total forest carbon stock for the forest in 2000 was estimated at 5,974 Million t C, with Western province contributing the most (802 Million t C), and Manus province contributing the least (22 Million t C).

Table P-4. Province-level estimates of above and belowground forest biomass carbon stocks expressed as area weighted average (t C ha^{-1}) and total carbon (t C)

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Million t C)
1	Central	175	458
2	Chimbu	152	86
3	East New Britain	172	241
4	East Sepik	171	528
5	Eastern Highlands	146	129
6	Enga	151	167
7	Gulf	177	558
8	Madang	180	452
9	Manus	139	22
10	Milne Bay	151	178
11	Morobe	163	437
12	New Ireland	147	119
13	North Solomons	135	96
14	Northern	175	364
15	Sandaun	177	519
16	Southern Highlands	161	389
17	West New Britain	166	310
18	Western	115	802
19	Western Highlands	153	119
	Papua New Guinea	**158**	**5,974**

6.1.5 Carbon emissions from deforestation

Annual carbon emissions from deforestation between 2000 and 2005 for Papua New Guinea are shown in Figure P-5. Table P-5 reports the annual emissions from deforestation per province.

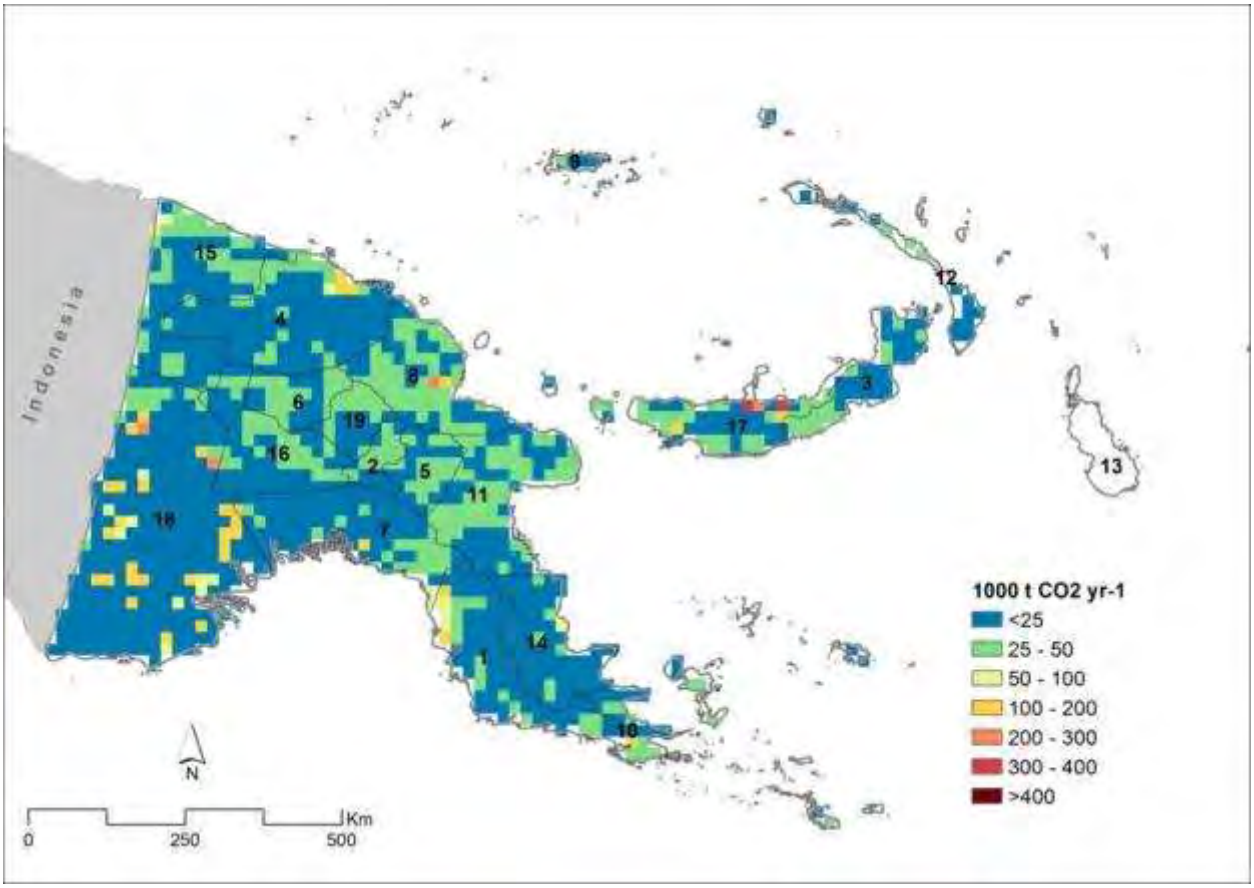


Figure P-5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 200-2005 for Papua New Guinea. Provinces are labeled according to 'Map ID' information provided in Table P-5.

Western province was found to have the highest annual CO_2 emissions from deforestation (5,725,000 t CO_2 yr^{-1}), followed by West New Britain province (2,160,000 t CO_2 yr^{-1}). Manus was found to have the lowest annual CO_2 emissions of deforestation between 2000 and 2005 (82,000 t CO_2 yr^{-1}).

Table P-5. Province level estimates of carbon emissions (t CO_2 yr^{-1}) from deforestation between 2000 and 2005

Map ID	Province	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
1	Central	1,395
2	Chimbu	403
3	East New Britain	564
4	East Sepik	1,909
5	Eastern Highlands	705
6	Enga	769
7	Gulf	1,307
8	Madang	2,422
9	Manus	82
10	Milne Bay	793
11	Morobe	2,099
12	New Ireland	457
13	North Solomons*	-
14	Northern	555
15	Sandaun	1,886
16	Southern Highlands	1,107
17	West New Britain	2,394
18	Western	5,881
19	Western Highlands	564
	Papua New Guinea	**25,294**

** No annual emissions from deforestation for this province*

6.2 FACTORS FOR NATIONAL CIRCUMSTANCES

This section illustrates seven key factors that are often used to explain patterns of deforestation across Papua New Guinea. Factors for roads and settlements were obtained from University of Papua New Guinea (UPNG) Remote Sensing Center[7], while the remaining factors are subsets from the regional factors presented in the regional Atlas (section 3.2). The data on settlements from UPNG reported population census data for each settlement for 2000 and 2008 in the database. Change in population between 2000 and 2008 was estimated based on this data as the difference in population between the two years and the difference expressed as a percentage of the 2000 density for each settlement. The change in population density across all settlements was averaged and reported at the province level. Maps of elevation, roads, settlements (populated places), climate zones, soil nutrient availability, protected areas and rural population growth are shown in Figures P-6-12.

6.2.1 Elevation

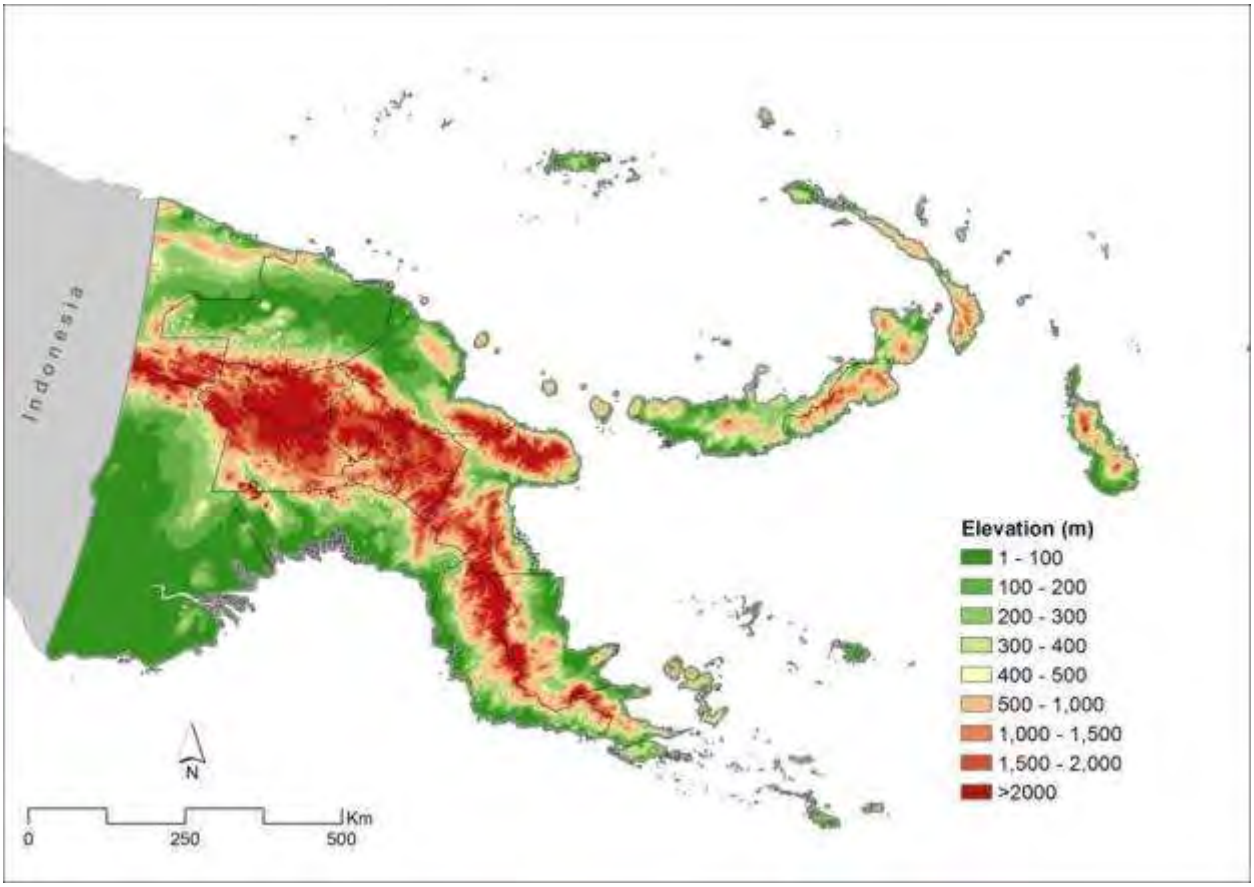


Figure P-6. Elevation across Papua New Guinea.

[7] http://gis.mortonblacketer.com.au/upngis/instructions.htm

6.2.2 Roads

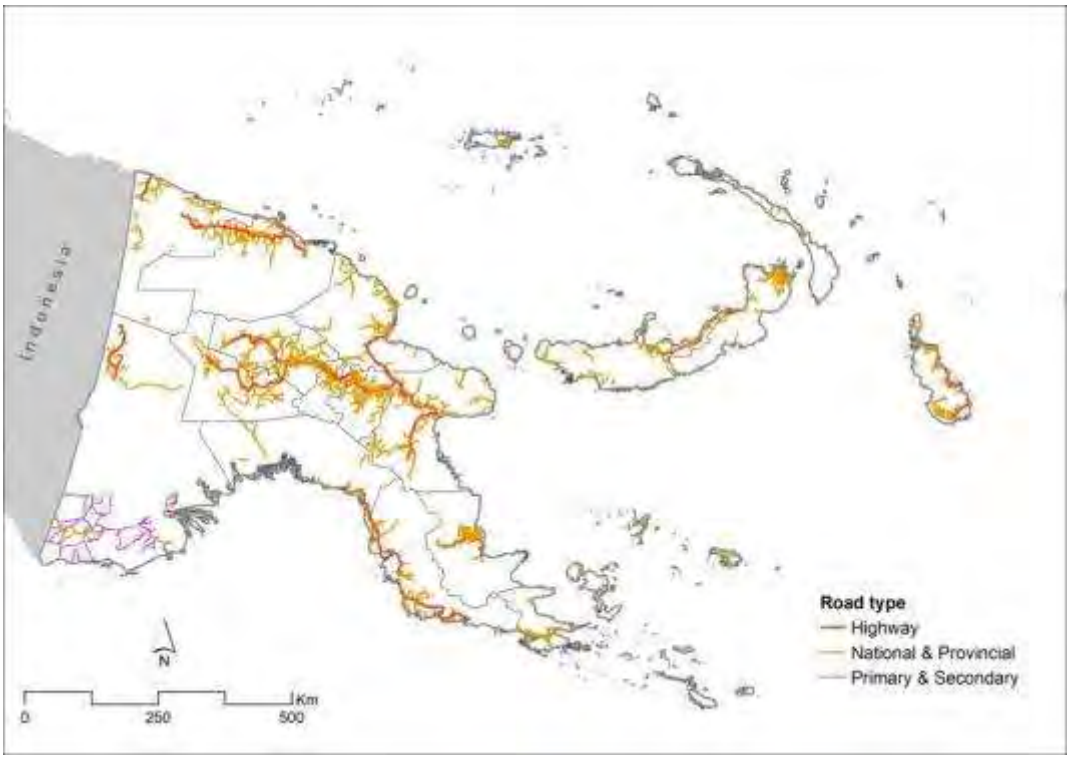


Figure P-7. Location of roads across Papua New Guinea.

6.2.3 Settlements

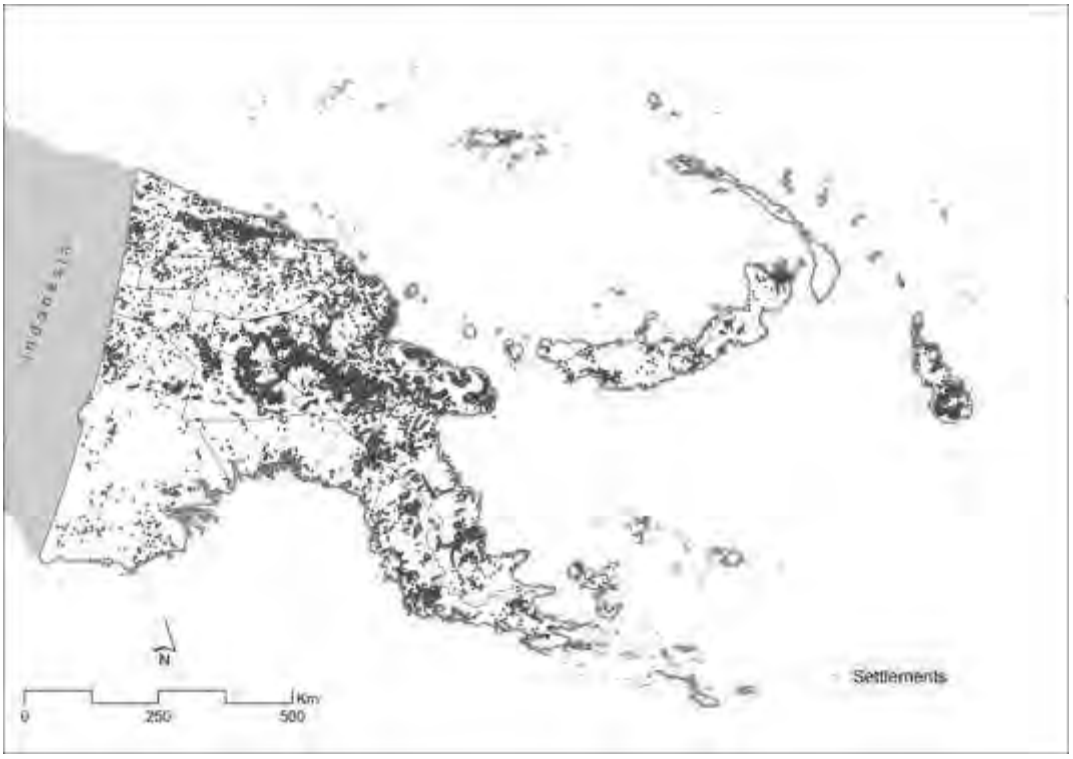


Figure P-8. Map of all settlements (populated places) across Papua New Guinea.

6.2.4 Climate

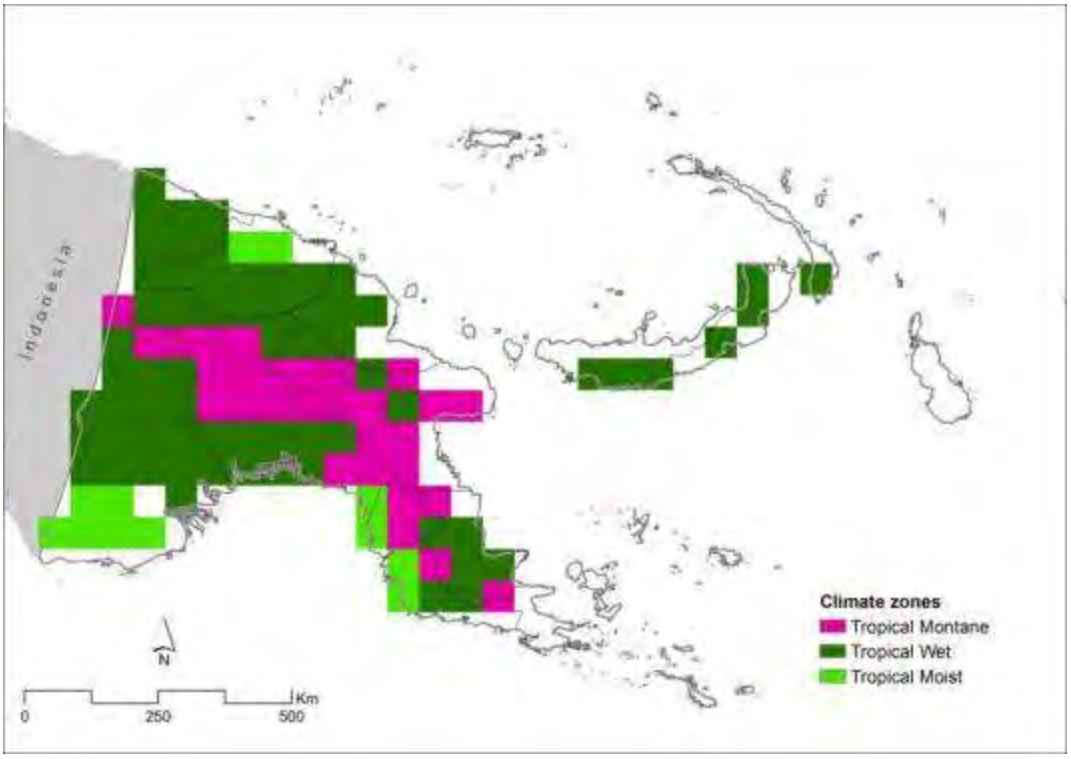


Figure P-9. Climate zones across Papua New Guinea.

6.2.5 Soil nutrient availability

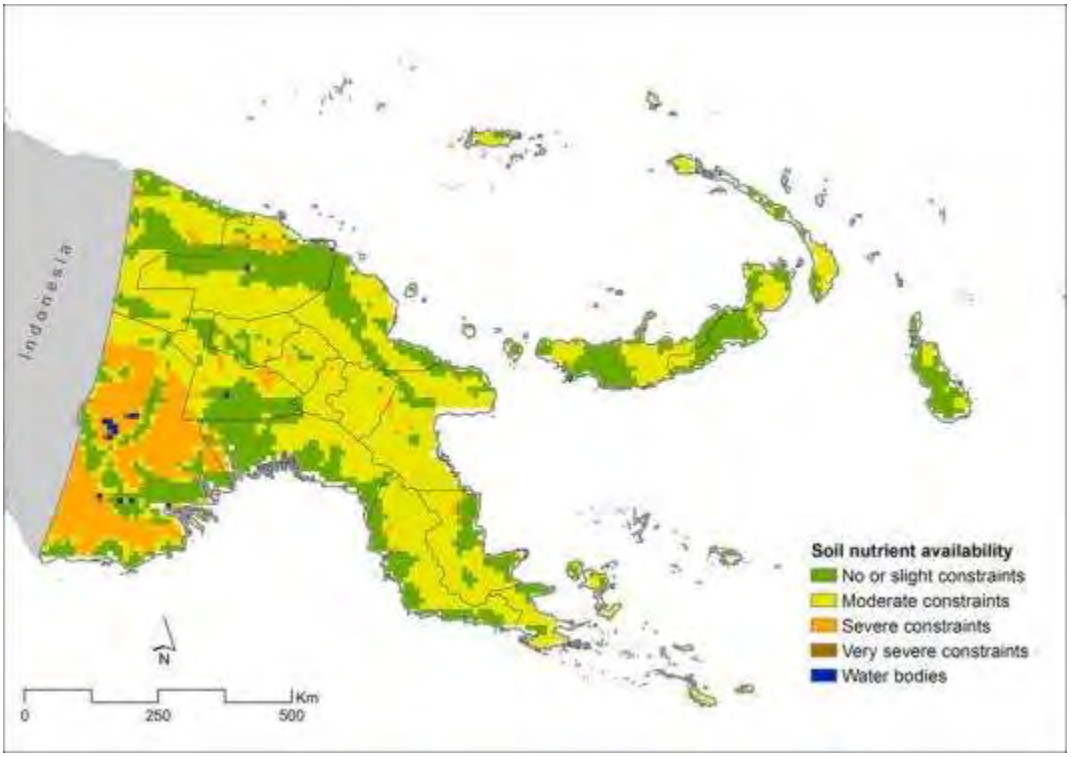


Figure P-10. Soil nutrient availability ranges across Papua New Guinea.

6.2.6 Rural population growth

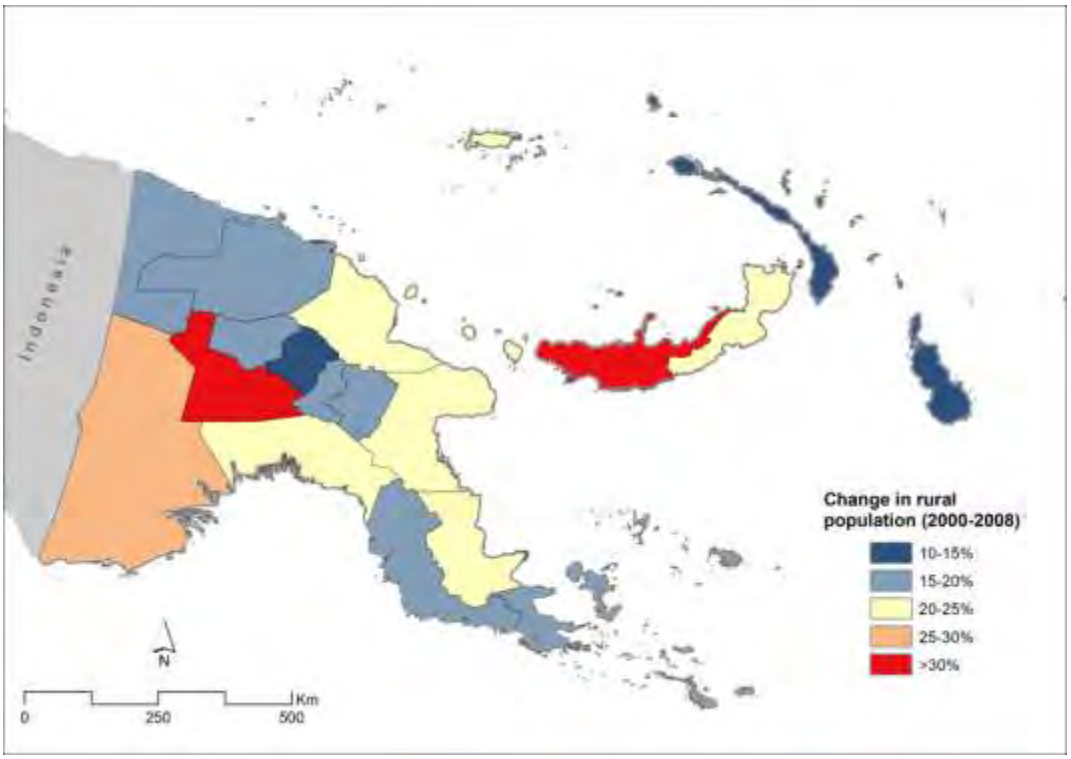


Figure P-11. Rural population growth shown as percent change in population.

6.2.7 Protected areas

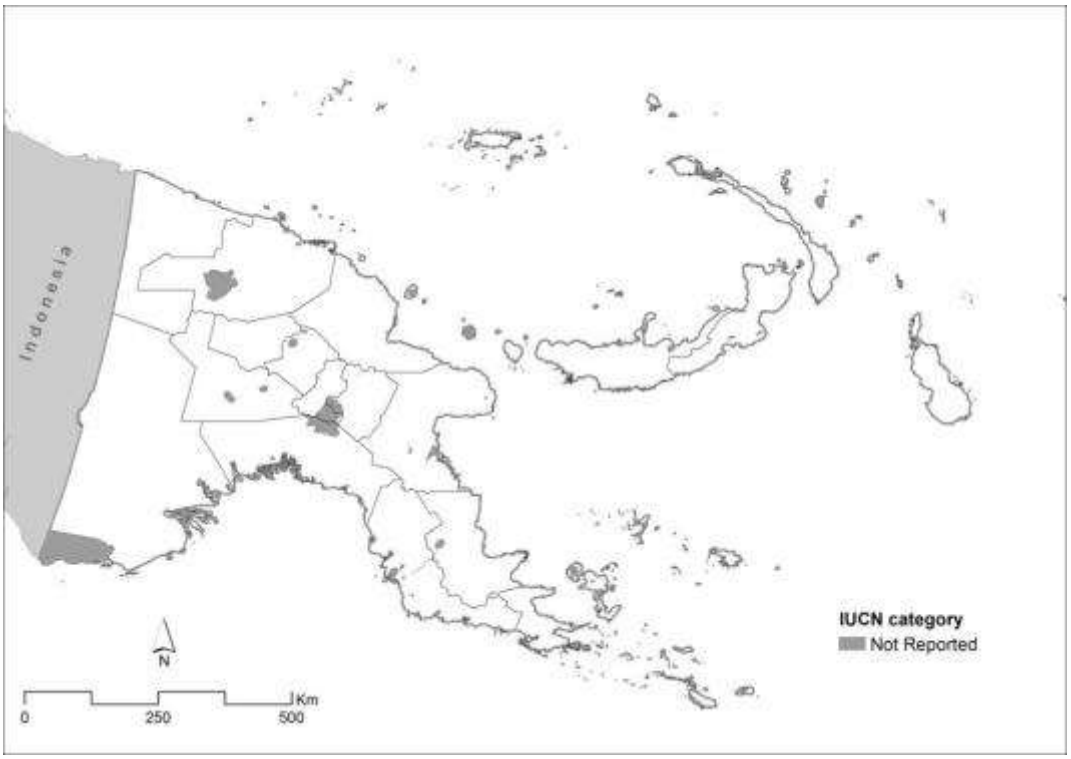


Figure P-12. Map of protected areas by IUCN category.

6.3 FOREST THREATS

This section presents spatial overlays of different factors over the 2000 map of forest cover (defined as at least 25% tree cover from MODIS VCF data) to illustrate possible threats to the forest in Papua New Guinea in terms of potential for future deforestation. These spatial overlays present several examples of how different threat for forests can be mapped with country-specific data. These examples use coarse resolution global datasets, and more detailed analysis can be done using country/province-specific data for key factors of interest.

6.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forest to other land uses depends on the amount carbon stored in the forest. Understanding where forests with high carbon stocks, and thus potential for high emissions from deforestation, are located within Papua New Guinea could provide input to decisions regarding land use planning in the country.

Figure P-13 illustrates the distribution of carbon stocks across forests in Papua New Guinea. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}).

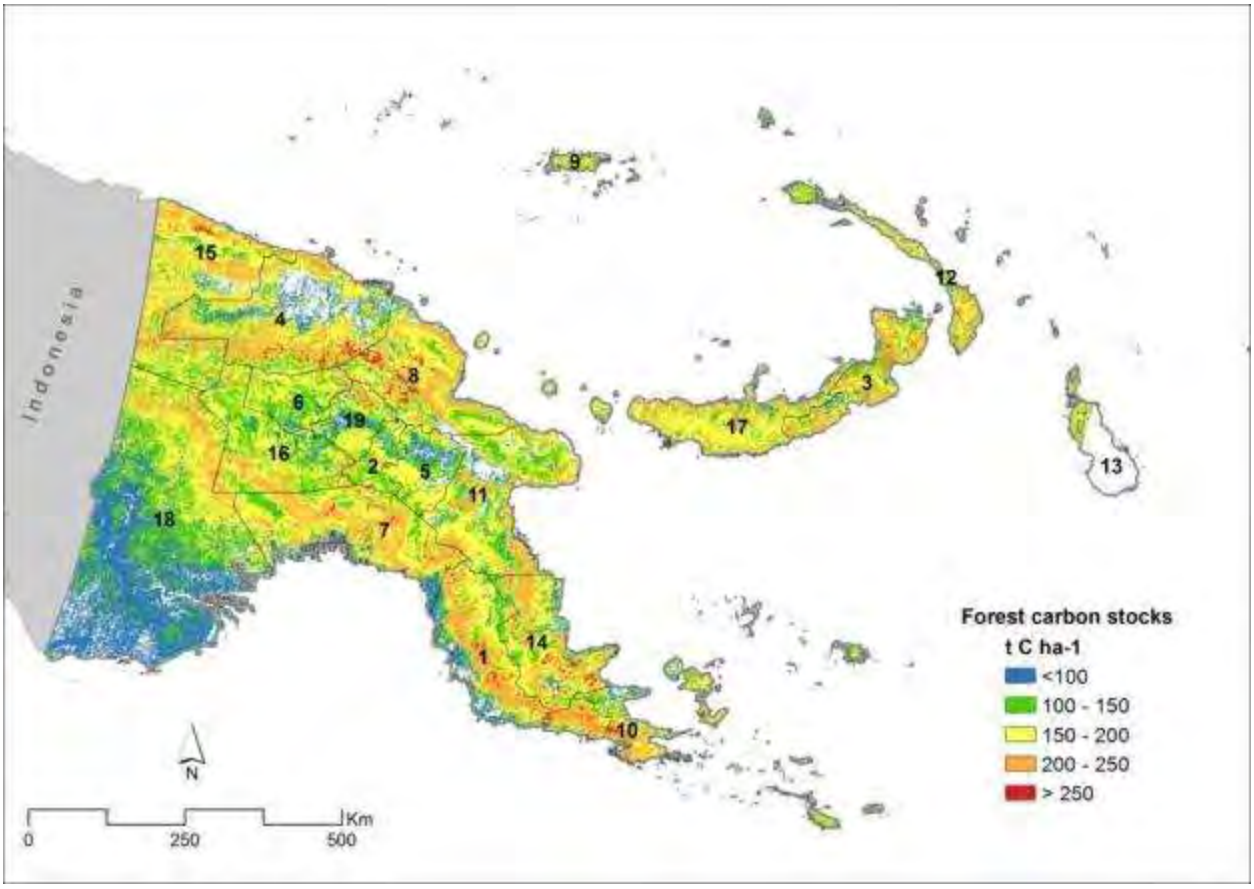


Figure P-13. Forest carbon stocks for forest cover in 2000 across Papua New Guinea.

Table P-6 reports the percentage of forests per carbon stock category for provinces in Papua New Guinea. The largest part of the forests was classified in MEDIUM HIGH carbon category (41%), followed by the MEDIUM carbon category (22%) and the least area of the forest was classified in VERY HIGH carbon category (1%).

Table P-6. Sub-national estimates as percent forest cover per carbon stock category. Carbon stocks categories are defined as LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150-200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (< 250 t C ha^{-1}).

Map ID	Provinces	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
1	Central	2,612	3	35	35	16	10
2	Chimbu	575	1	6	46	40	7
3	East New Britain	1,417	2	32	35	21	9
4	East Sepik	3,122	3	29	42	16	11
5	Eastern Highland	895	0	2	53	31	13
6	Enga	1,121	1	3	52	38	6
7	Gulf	3,211	1	31	46	15	7
8	Madang	2,538	4	28	47	16	5
9	Manus	150	0	14	36	28	22
10	Milne Bay	1,153	2	24	31	22	22
11	Morobe	2,712	1	18	49	24	8
12	New Ireland	792	0	21	33	22	23
13	North Solomons*	185	0	17	27	23	33
14	Northern	2,113	3	27	45	18	6
15	Sandaun	2,976	1	26	53	16	4
16	Southern Highlan	2,464	1	13	50	32	5
17	West New Britain	1,868	0	20	53	17	10
18	Western	7,081	0	7	24	27	42
19	Western Highland	796	2	9	48	29	13
	Papua New Guinea	**37,781**	**1**	**20**	**41**	**22**	**15**

** Forest carbon stock spatial data is not available for the entire province of North Solomons. The percent forests in each carbon category is estimated only for the overlapping forest and carbon stock data area.*

6.3.2 Analysis #2: Forest and agriculture suitability

Most forests are cleared for agriculture (small or large scale), and soil nutrient availability is a key factor that can be used to predict potential future threat to the forest. Figure P-14 illustrates the potential suitability for agriculture across forest areas in 2000 based on soil nutrient availability. Forests with slight to moderate constraints based on soil nutrient availability were considered more suitable, while forests with severe and very severe constraints were considered not suitable for agriculture. Figure P-15 illustrates the distribution of the carbon stock categories across forests with potential suitability for agriculture use in Papua New Guinea.

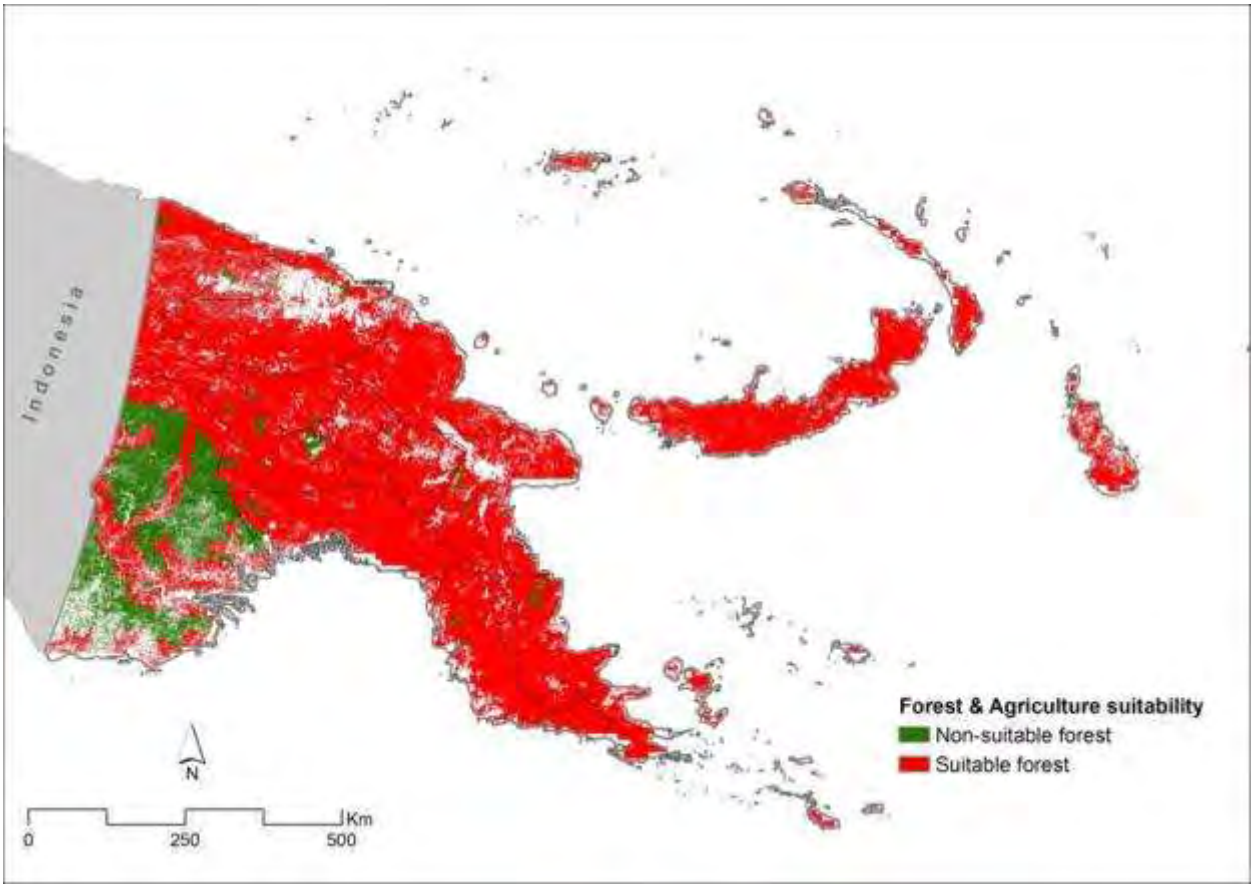


Figure P-14. Spatial overlay of forests areas in 2000 with no or slight to moderate constraints (red) and with high and very high (green) constraints on soil nutrient availability for Papua New Guinea.

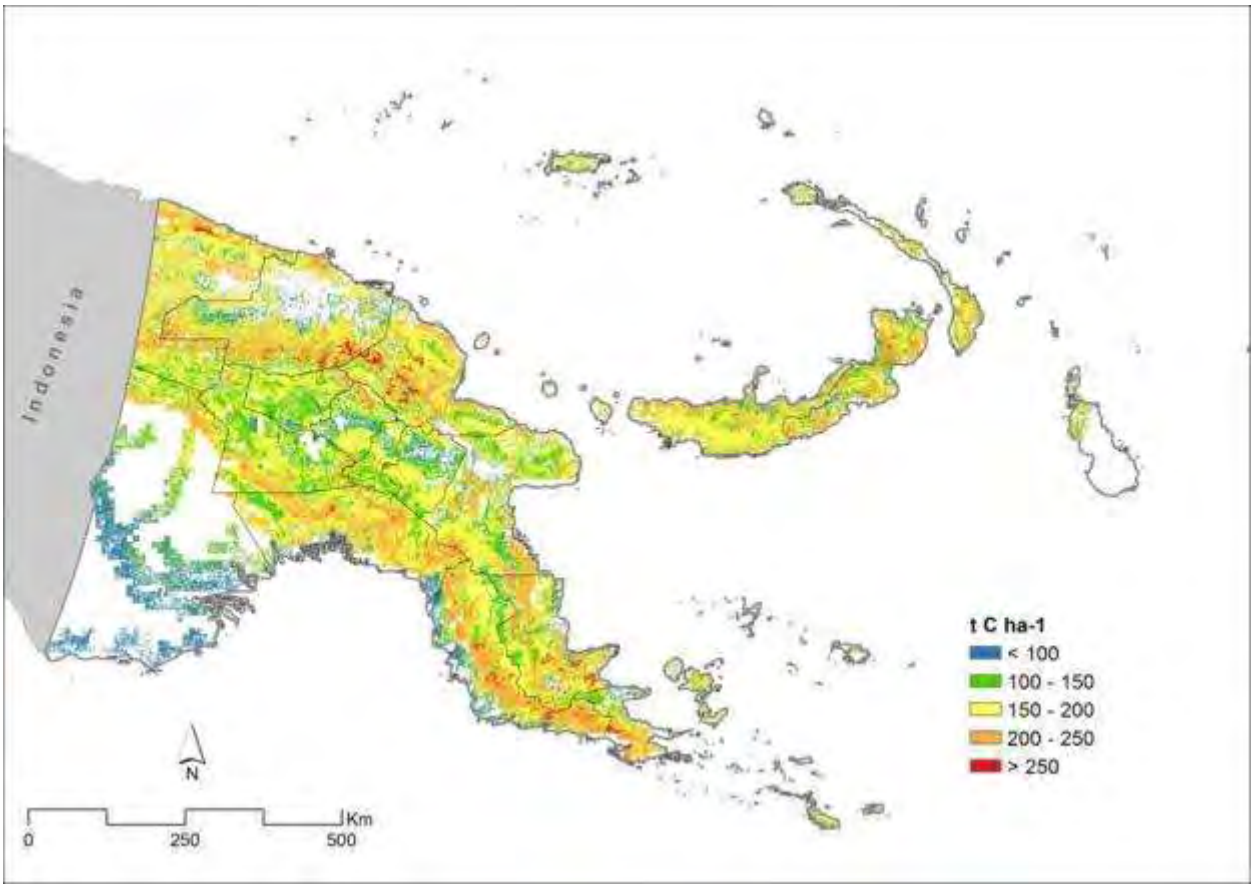


Figure P-15. Spatial overlay of forest lands suitable for agriculture and their respective forest carbon stocks.

6.3.3 Analysis #3: Forest and road network

Forests close to roads are more likely to be deforested or disturbed than forests further away from roads. Using the assumption that forest within 5km from the roads is more accessible, Figure P-16 illustrates accessibility of forests in Papua New Guinea. Figure P-17 illustrates the distribution of carbon stock categories across the more accessible forest, as defined within the 5 km buffer zone around the roads.

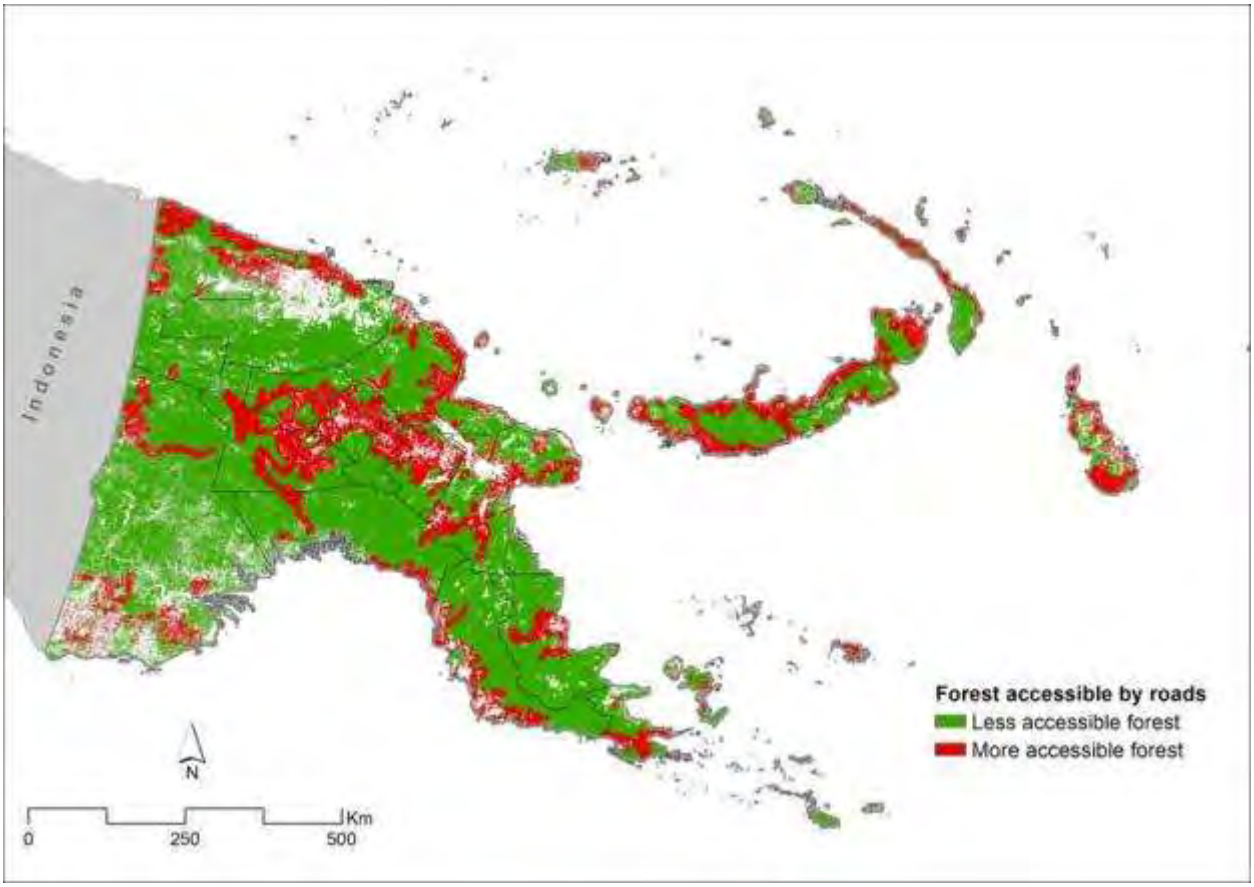


Figure P-16. Spatial overlay of forest cover in 2000 and 5 km buffer zone around road network in Papua New Guinea. More accessible forests are defined as forests within 5 km buffer zone and less accessible forests are defined as forests outside this zone.

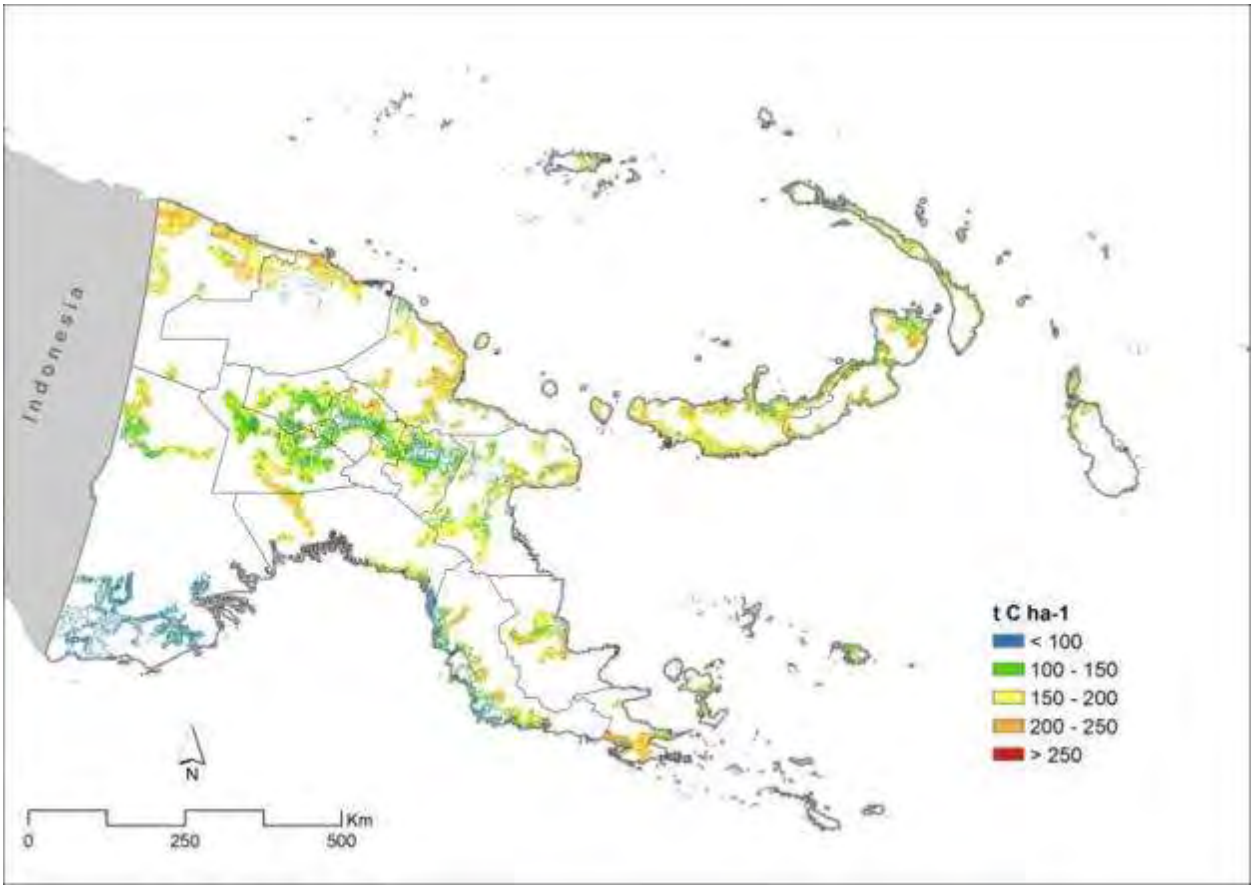


Figure P-17. Spatial overlay of more accessible forest (within 5 km buffer zone around roads) and carbon stocks.

6.3.4 Analysis #4: Forest and change in population

Increases in rural population can result in increased potential threat to forests. Figure P-18 illustrates the change in population based on population data for 2000 and 2008. Rural population in the northwest and more southeastern provinces experienced less than 20% change, while the rural population in the east and western provinces experienced between 20% and 30% change for the 2000-2008. Only two provinces experienced change in rural population more than 30%, which present an elevated threat to their forests.

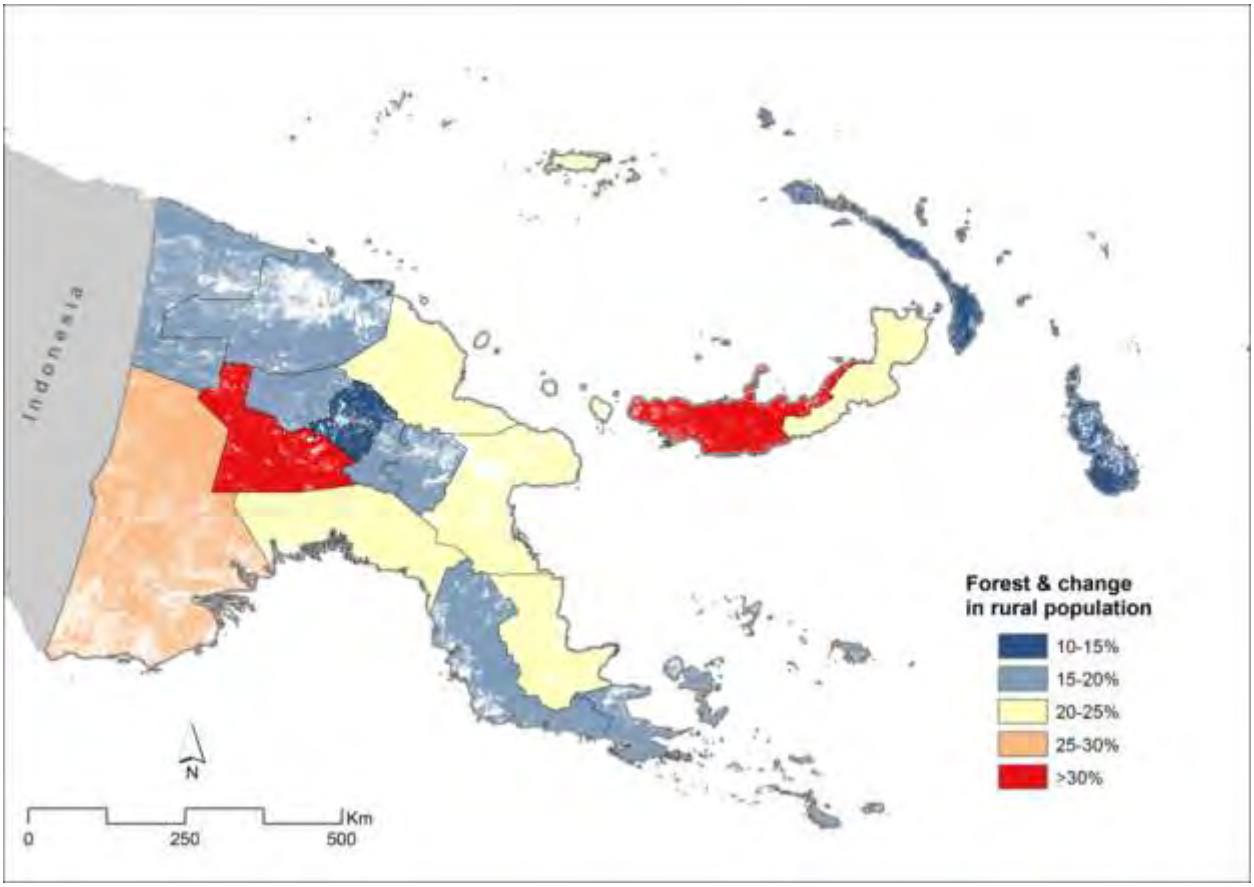


Figure P-18. Spatial overlay of forest cover and change in rural population between 2000 and 2008

6.3.5 Analysis #5: Forest and elevation

In most cases deforestation occurs at low elevation, where people usually live. To illustrate the potential threat to forests based on elevation, Figure P-19 shows the forest across Papua New Guinea in three elevation categories: low (1-500m), medium (500-1,500m) and high (>1,500m). Most of the forests are located at low elevation. Forests at medium and high elevation are concentrated in the central part of the country, and would be considered at lower risk of deforestation based on this criterion.

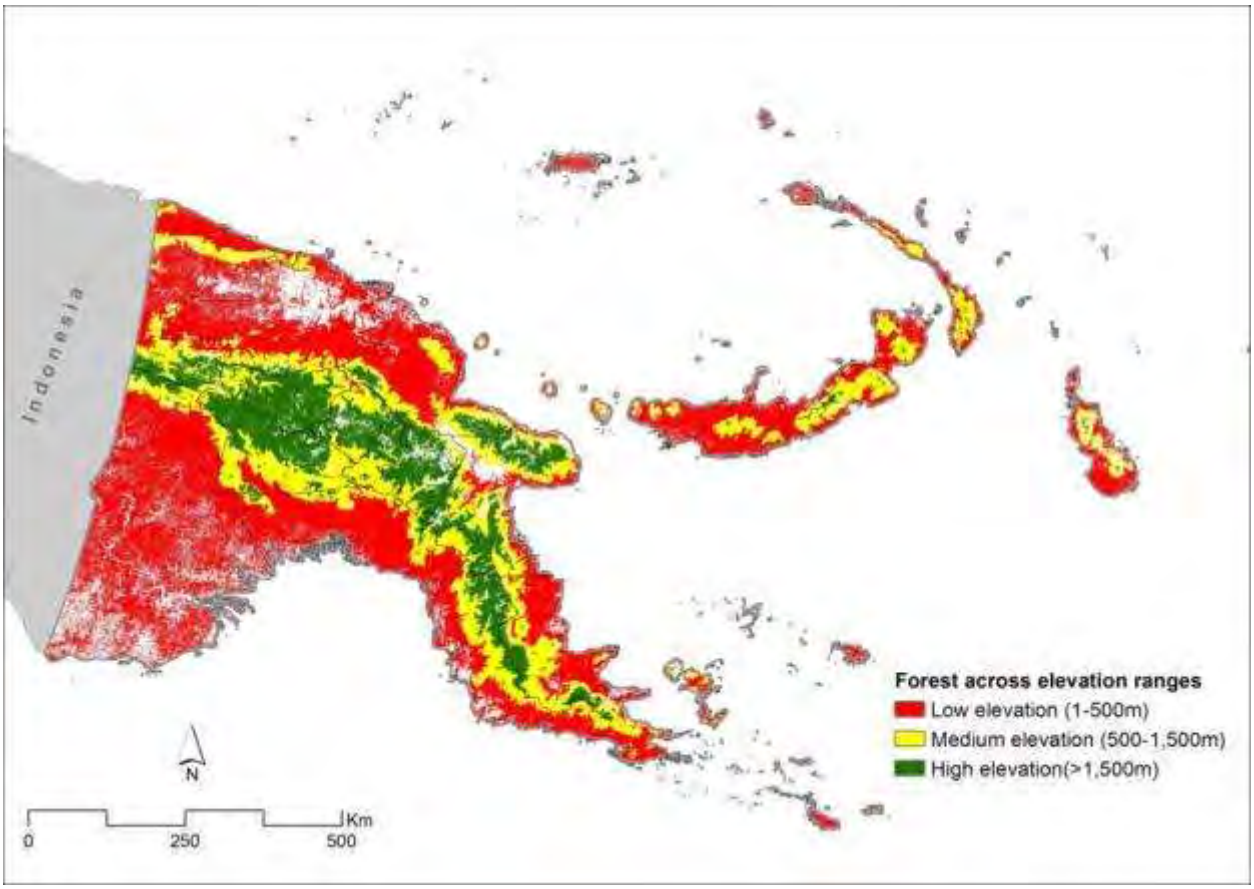


Figure P-19. Forest cover in Papua New Guinea for 2000 by elevation classes

7. THAILAND

This section presents the same maps and statistics given in the South and Southeast Asia Atlas (Chapter 2) reported at the subnational level for Thailand. These highlight key factors that should be considered for defining national circumstances, and illustrate forest threats based on roads, change in population density, elevation and suitability for agriculture based on nutrient availability.

7.1 NATIONAL STATISTICS RELATED TO REDD+

7.1.1 Forest cover

Figure T-1 shows the extent of forest cover in 2000 across the provinces in Thailand, and Table T-1 reports the forest coverage per province and percent of the province area covered by forest.

Figure T-1. Forest cover in 2000 across Thailand. Forest cover is defined greater than 25% tree cover from MODIS VCF data. Provinces are labeled according to 'Map ID' information provided in Table T-1.

According to spatial data, 31% of the total forest area was forested. Mae Hong province had the largest extent of forest cover (90%), while Maha Sarakham had the smallest extent of forest cover less than 0%.

Table T-1. Province-level estimates of forests and percent of province area in forest cover for 2000

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
1	Amnat Charoen	325	32	10%
2	Ang Thong	95	5	6%
3	Bangkok Metropolis	157	1	1%
4	Buri Ram	1,011	65	6%
5	Chachoengsao	524	73	14%
6	Chai Nat	248	12	5%
7	Chaiyaphum	1,271	293	23%
8	Chanthaburi	629	217	35%
9	Chiang Mai	2,217	1,494	67%
10	Chiang Rai	1,161	392	34%
11	Chon Buri	449	28	6%
12	Chumphon	603	264	44%
13	Kalasin	692	30	4%
14	Kamphaeng Phet	866	173	20%
15	Kanchanaburi	1,942	926	48%
16	Khon Kaen	1,064	69	7%
17	Krabi	487	296	61%
18	Lampang	1,256	712	57%
19	Lamphun	450	206	46%
20	Loei	1,057	289	27%
21	Lop Buri	628	15	2%
22	Mae Hong Son	1,273	1,149	90%
23	Maha Sarakham	562	2	0%
24	Mukdahan	418	82	20%
25	Nakhon Nayok	215	64	30%
26	Nakhon Pathom	215	11	5%
27	Nakhon Phanom	547	47	9%
28	Nakhon Ratchasima	2,076	229	11%
29	Nakhon Sawan	954	73	8%
30	Nakhon Si Thammarat	995	455	46%
31	Nan	1,227	798	65%
32	Narathiwat	448	258	58%
33	Nong Bua Lam Phu	414	22	5%
34	Nong Khai	724	43	6%
35	Nonthaburi	64	1	2%
36	Pathum Thani	152	3	2%
37	Pattani	196	48	25%
38	Phangnga	401	267	67%
39	Phatthalung	338	86	26%
40	Phayao	613	292	48%
41	Phetchabun	1,243	318	26%
42	Phetchaburi	620	307	50%
43	Phichit	433	20	5%

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
44	Phitsanulok	1,063	338	32%
45	Phra Nakhon Si Ayutthaya	256	11	4%
46	Phrae	650	375	58%
47	Phuket	56	22	39%
48	Prachin Buri	501	130	26%
49	Prachuap Khiri Khan	644	239	37%
50	Ranong	314	216	69%
51	Ratchaburi	520	100	19%
52	Rayong	371	33	9%
53	Roi Et	783	14	2%
54	Sa Kaeo	692	124	18%
55	Sakon Nakhon	956	105	11%
56	Samut Prakan	94	3	3%
57	Samut Sakhon	86	8	9%
58	Samut Songkhram	41	19	46%
59	Saraburi	358	40	11%
60	Satun	270	150	56%
61	Si Sa Ket	890	87	10%
62	Sing Buri	84	2	2%
63	Songkhla	726	221	30%
64	Sukhothai	672	170	25%
65	Suphan Buri	544	48	9%
66	Surat Thani	1,317	656	50%
67	Surin	884	50	6%
68	Tak	1,727	1,142	66%
69	Trang	487	245	50%
70	Trat	287	123	43%
71	Ubon Ratchathani	1,553	190	12%
72	Udon Thani	1,110	60	5%
73	Uthai Thani	668	288	43%
74	Uttaradit	783	395	50%
75	Yala	445	331	74%
76	Yasothon	411	12	3%
	Thailand	**51,504**	**16,114**	**31%**

7.1.2 Forest cover in protected areas

Figure T-2 illustrates forest area within protected areas, and Table T-2 reports the actual forest area and percent forest in protected area per province.

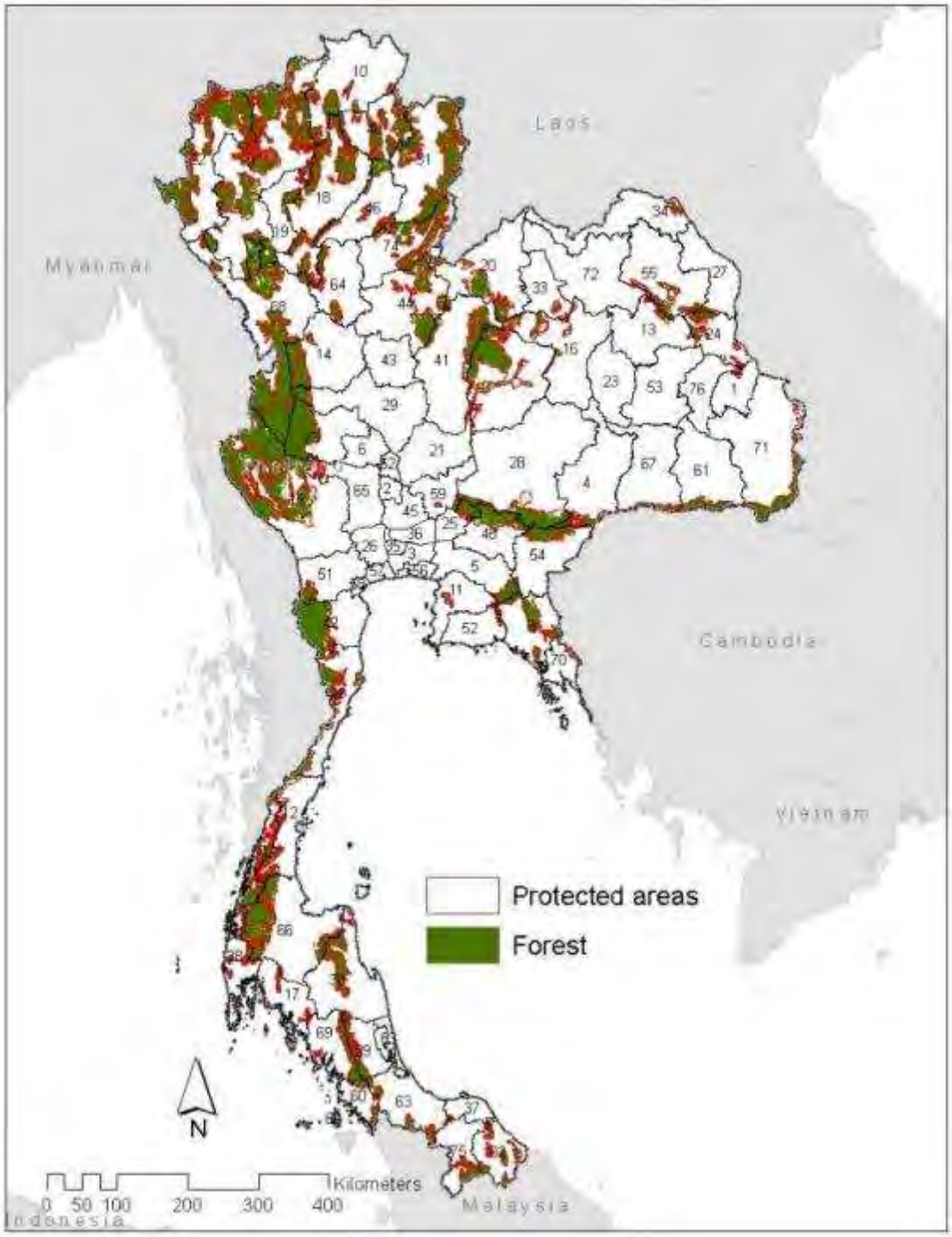


Figure T-2. Distribution of forest cover in 2000 within protected area Thailand. Provinces are labeled according to 'Map ID' information provided in Table 2.

The province with the highest percent forest in protected area is Prachin Buri (93%), with 121,000 ha protected forest. The province with at least percent forest in protected area is Undou Thani province (4%), with 3,000 ha protected forest. Fourteen provinces do not have any protected forests.

Table T-2. Province-level estimates of forests in protected areas and percent protected forests of the total forest area in Thailand

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
1	Amnat Charoen	4	14%
2	Ang Thong	0	0%
3	Bangkok Metropolis	0	0%
4	Buri Ram	56	86%
5	Chachoengsao	55	75%
6	Chai Nat	0	0%
7	Chaiyaphum	242	83%
8	Chanthaburi	128	59%
9	Chiang Mai	763	51%
10	Chiang Rai	112	29%
11	Chon Buri	13	46%
12	Chumphon	95	36%
13	Kalasin	14	44%
14	Kamphaeng Phet	144	83%
15	Kanchanaburi	779	84%
16	Khon Kaen	52	75%
17	Krabi	32	11%
18	Lampang	332	47%
19	Lamphun	94	46%
20	Loei	121	42%
21	Lop Buri	1	9%
22	Mae Hong Son	602	52%
23	Maha Sarakham	0	0%
24	Mukdahan	56	68%
25	Nakhon Nayok	56	88%
26	Nakhon Pathom	0	0%
27	Nakhon Phanom	10	22%
28	Nakhon Ratchasima	165	72%
29	Nakhon Sawan	44	59%
30	Nakhon Si Thammarat	148	33%
31	Nan	424	53%
32	Narathiwat	78	30%
33	Nong Bua Lam Phu	8	35%
34	Nong Khai	11	26%
35	Nonthaburi	0	0%
36	Pathum Thani	0	0%
37	Pattani	3	6%
38	Phangnga	64	24%

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
39	Phatthalung	56	65%
40	Phayao	213	73%
41	Phetchabun	157	49%
42	Phetchaburi	264	86%
43	Phichit	0	0%
44	Phitsanulok	190	56%
45	Phra Nakhon Si Ayutthaya	0	0%
46	Phrae	116	31%
47	Phuket	3	15%
48	Prachin Buri	121	93%
49	Prachuap Khiri Khan	150	63%
50	Ranong	141	65%
51	Ratchaburi	43	43%
52	Rayong	10	29%
53	Roi Et	0	0%
54	Sa Kaeo	103	83%
55	Sakon Nakhon	67	64%
56	Samut Prakan	0	0%
57	Samut Sakhon	0	0%
58	Samut Songkhram	0	0%
59	Saraburi	11	29%
60	Satun	58	39%
61	Si Sa Ket	66	76%
62	Sing Buri	0	0%
63	Songkhla	63	28%
64	Sukhothai	59	35%
65	Suphan Buri	14	29%
66	Surat Thani	349	53%
67	Surin	37	73%
68	Tak	741	65%
69	Trang	89	36%
70	Trat	39	31%
71	Ubon Ratchathani	133	70%
72	Udon Thani	3	4%
73	Uthai Thani	255	89%
74	Uttaradit	234	59%
75	Yala	63	19%
76	Yasothon	3	27%
	Thailand	**8,558**	**53%**

7.1.3 Gross Forest Cover Loss

The annual gross forest cover loss between 2000 and 2005 is shown in Figure T-3, with a summary of the actual values presented in Table T-3.

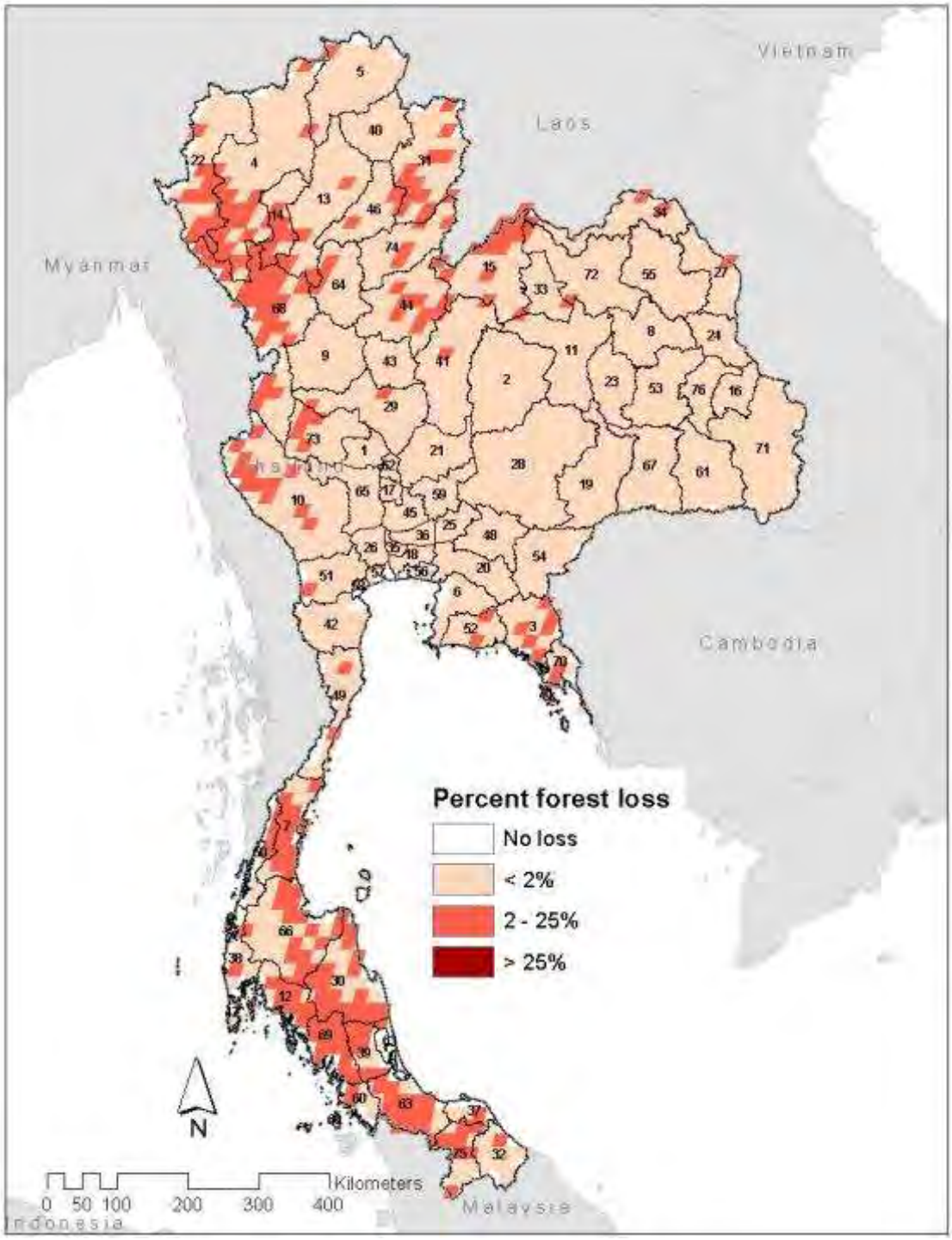


Figure T-3. Distribution of gross forest cover loss between 2000 and 2005 across Thailand. Provinces are labeled according to 'Map ID' information provided in Table 3.

Maha Sarakham, with 28%, is the province with highest gross forest loss expressed as a percent of the forests in 2000. Phetchaburi, with 0.1%, is the province with lowest gross forest loss expressed as percent of the forest cover in 2000.

Table T-3. Province-level estimates of average annual gross forest cover loss between 2000 and 2005 expressed as hectares and percent of the forest cover in 2000

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
1	Amnat Charoen	353	1.1%
2	Ang Thong	12	0.2%
3	Bangkok Metropolis	20	1.4%
4	Buri Ram	989	1.5%
5	Chachoengsao	185	0.3%
6	Chai Nat	142	1.2%
7	Chaiyaphum	1,323	0.5%
8	Chanthaburi	2,662	1.2%
9	Chiang Mai	11,154	0.7%
10	Chiang Rai	1,717	0.4%
11	Chon Buri	383	1.4%
12	Chumphon	4,050	1.5%
13	Kalasin	706	2.3%
14	Kamphaeng Phet	749	0.4%
15	Kanchanaburi	6,069	0.7%
16	Khon Kaen	1,044	1.5%
17	Krabi	2,356	0.8%
18	Lampang	3,186	0.4%
19	Lamphun	2,741	1.3%
20	Loei	3,143	1.1%
21	Lop Buri	553	3.6%
22	Mae Hong Son	5,108	0.4%
23	Maha Sarakham	530	28.0%
24	Mukdahan	424	0.5%
25	Nakhon Nayok	138	0.2%
26	Nakhon Pathom	28	0.3%
27	Nakhon Phanom	565	1.2%
28	Nakhon Ratchasima	2,048	0.9%
29	Nakhon Sawan	1,957	2.7%
30	Nakhon Si Thammarat	9,693	2.1%
31	Nan	3,956	0.5%
32	Narathiwat	949	0.4%
33	Nong Bua Lam Phu	357	1.7%
34	Nong Khai	849	2.0%
35	Nonthaburi	8	0.6%
36	Pathum Thani	12	0.4%
37	Pattani	603	1.3%
38	Phangnga	1,243	0.5%
39	Phatthalung	1,639	1.9%
40	Phayao	597	0.2%

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr^{-1})	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
41	Phetchabun	1,575	0.5%
42	Phetchaburi	296	0.1%
43	Phichit	264	1.3%
44	Phitsanulok	2,945	0.9%
45	Phra Nakhon Si Ayutthaya	24	0.2%
46	Phrae	1,788	0.5%
47	Phuket	51	0.2%
48	Prachin Buri	248	0.2%
49	Prachuap Khiri Khan	965	0.4%
50	Ranong	1,432	0.7%
51	Ratchaburi	381	0.4%
52	Rayong	357	1.1%
53	Roi Et	777	5.4%
54	Sa Kaeo	1,703	1.4%
55	Sakon Nakhon	953	0.9%
56	Samut Prakan	8	0.3%
57	Samut Sakhon	0	0.0%
58	Samut Songkhram	0	0.0%
59	Saraburi	232	0.6%
60	Satun	924	0.6%
61	Si Sa Ket	918	1.1%
62	Sing Buri	8	0.5%
63	Songkhla	4,370	2.0%
64	Sukhothai	1,290	0.8%
65	Suphan Buri	327	0.7%
66	Surat Thani	5,855	0.9%
67	Surin	989	2.0%
68	Tak	14,383	1.3%
69	Trang	6,325	2.6%
70	Trat	1,145	0.9%
71	Ubon Ratchathani	1,589	0.8%
72	Udon Thani	1,094	1.8%
73	Uthai Thani	2,099	0.7%
74	Uttaradit	1,813	0.5%
75	Yala	1,785	0.5%
76	Yasothon	459	3.7%
	Thailand	**133,608**	**0.8%**

7.1.4 Biomass Carbon Stocks

Figure T-4 illustrates the distribution of biomass carbon stocks according to Saatchi et al. (2011) clipped to the boundary of Thailand.

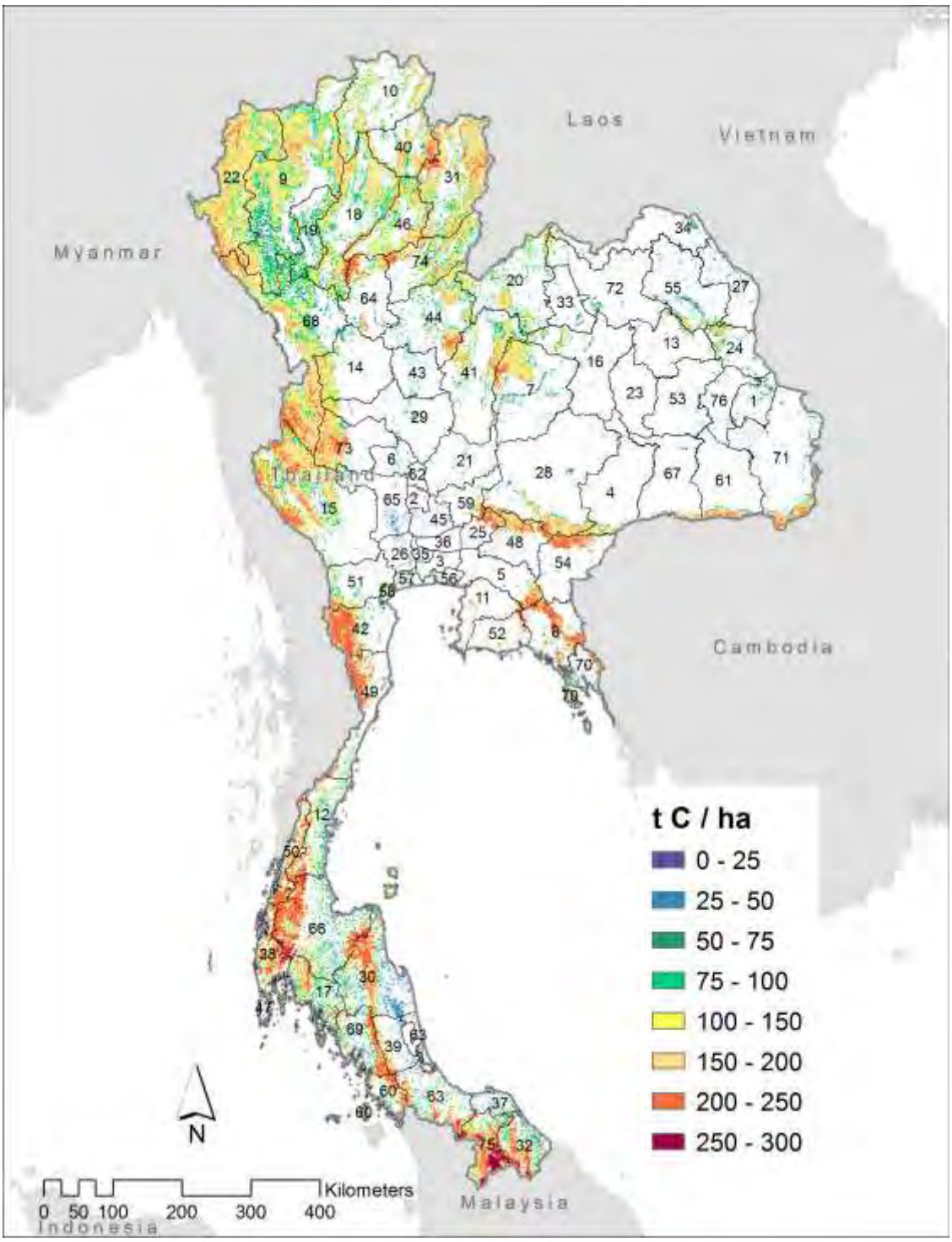


Figure T-4. Distribution of above and belowground forest biomass carbon stocks across Thailand. Provinces are labeled according to 'Map ID' information provided in Table T-4.

The forests in Yala province were with highest area weighted carbon stocks (193 t C ha^{-1}), while forests in Samut Prakan province were with the lowest area weighted carbon stocks (32 t C ha^{-1}). The total forest carbon stock for the forest in 2000 was estimated at 3,028 Million t C, with Yasothon contributing the most with 755 Million t C. Ten provinces contributed to the total forest carbon stocks with less than 1 Million t C.

Table T-4. Province level estimates of above and belowground forest biomass carbon stocks expressed as area weighted average (t C ha^{-1}) and total carbon (t C)

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Millions t C)
1	Amnat Charoen	60	2
2	Ang Thong	46	0
3	Bangkok Metropolis	37	0
4	Buri Ram	131	8
5	Chachoengsao	170	12
6	Chai Nat	58	1
7	Chaiyaphum	138	40
8	Chanthaburi	176	38
9	Chiang Mai	129	192
10	Chiang Rai	135	53
11	Chon Buri	133	4
12	Chumphon	139	37
13	Kalasin	85	3
14	Kamphaeng Phet	135	23
15	Kanchanaburi	157	145
16	Khon Kaen	93	6
17	Krabi	119	35
18	Lampang	133	95
19	Lamphun	97	20
20	Loei	114	33
21	Lop Buri	63	1
22	Mae Hong Son	153	176
23	Maha Sarakham	34	0
24	Mukdahan	116	10
25	Nakhon Nayok	188	12
26	Nakhon Pathom	40	0
27	Nakhon Phanom	58	3
28	Nakhon Ratchasima	153	35
29	Nakhon Sawan	113	8
30	Nakhon Si Thammarat	130	59
31	Nan	155	124
32	Narathiwat	164	42
33	Nong Bua Lam Phu	52	1
34	Nong Khai	68	3
35	Nonthaburi	36	0
36	Pathum Thani	38	0
37	Pattani	76	4
38	Phangnga	159	42
39	Phatthalung	135	12
40	Phayao	153	45

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Millions t C)
41	Phetchabun	132	42
42	Phetchaburi	185	57
43	Phichit	63	1
44	Phitsanulok	131	44
45	Phra Nakhon Si Ayutthaya	38	0
46	Phrae	142	53
47	Phuket	95	2
48	Prachin Buri	176	23
49	Prachuap Khiri Khan	174	42
50	Ranong	167	36
51	Ratchaburi	138	14
52	Rayong	143	5
53	Roi Et	72	1
54	Sa Kaeo	183	23
55	Sakon Nakhon	83	9
56	Samut Prakan	32	0
57	Samut Sakhon	45	0
58	Samut Songkhram	113	2
59	Saraburi	136	5
60	Satun	133	20
61	Si Sa Ket	154	13
62	Sing Buri	47	0
63	Songkhla	142	31
64	Sukhothai	145	25
65	Suphan Buri	68	3
66	Surat Thani	160	105
67	Surin	130	7
68	Tak	145	166
69	Total	114	28
70	Trang	131	16
71	Trat	127	24
72	Ubon Ratchathani	124	7
73	Udon Thani	92	26
74	Uthai Thani	174	69
75	Uttaradit	137	45
76	Yala	193	2
76	Yasothon	47	755
	Thailand	**116**	**3,028**

7.1.5 Carbon emissions from deforestation

Annual carbon emissions from deforestation between 2000 and 2005 for Thailand are shown in Figure T-5. Table T-5 reports the annual emissions from deforestation per province. Total emissions from deforestation for Thailand were 38,132,000 t CO_2 yr^{-1}.

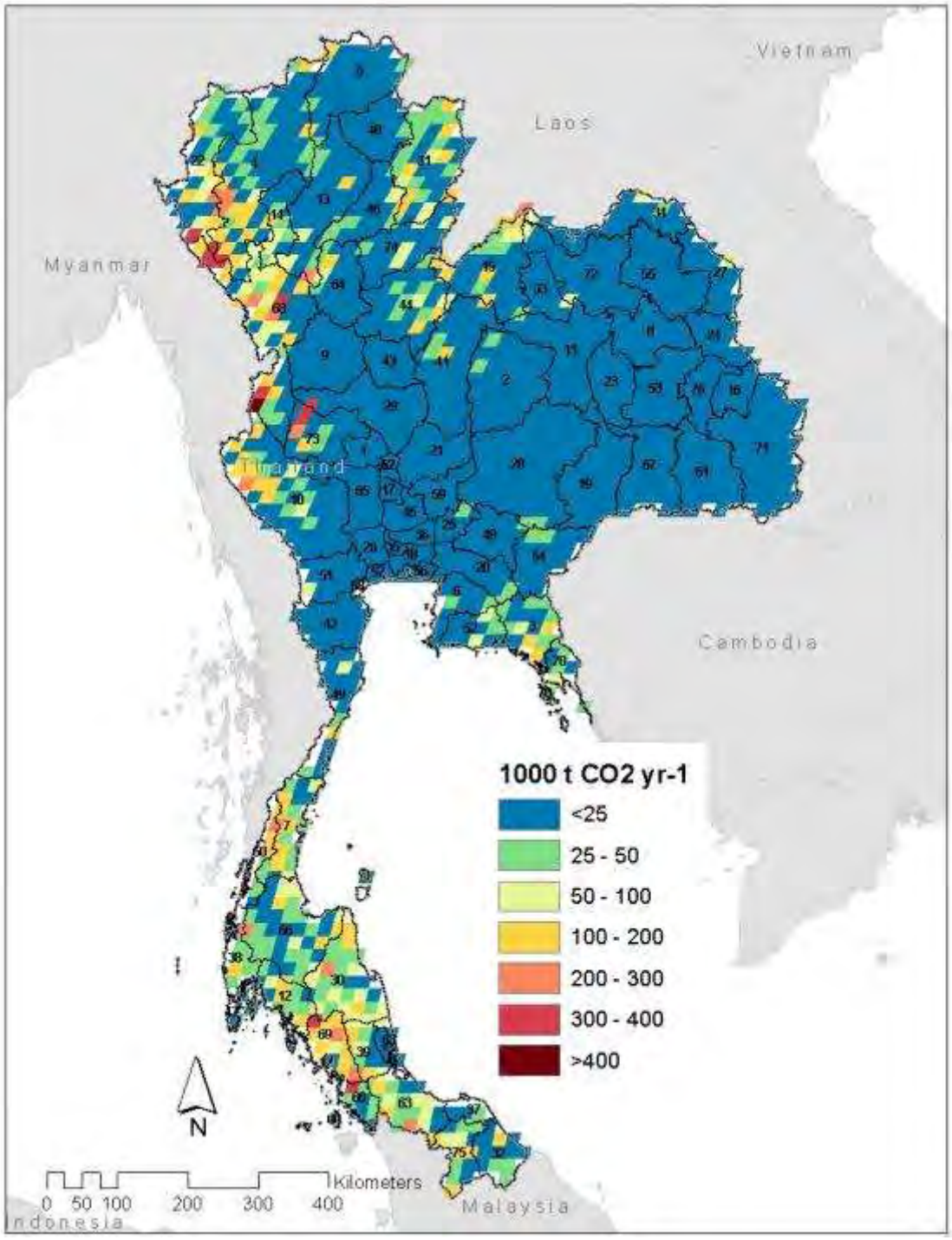


Figure T-5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005 for Thailand. Provinces are labeled according to 'Map ID' information provided in Table T-5.

Tak province was found to have the highest annual CO_2 emissions from deforestation (4,553,000 t CO_2 yr^{-1}), followed by Chiang Mai (3,466,000 t CO_2 yr^{-1}). Five provinces, Ang Thong, Nonthaburi, Samut Prakan, Pathum Thani and Sing Buri were found to have annual emissions from deforestation of 1,000 t CO_2 yr^{-1} , and two provinces, Samut Sakhon and Samut Songkhram, were found to have less that 1,000 t CO_2 yr^{-1}.

Table T-5. Province-level estimates of carbon emissions (t CO_2 yr^{-1}) from deforestation between 2000 and 2005

Map ID	Province	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
1	Amnat Charoen	43
2	Ang Thong	1
3	Bangkok Metropolis	2
4	Buri Ram	123
5	Chachoengsao	78
6	Chai Nat	15
7	Chaiyaphum	241
8	Chanthaburi	1,101
9	Chiang Mai	3,466
10	Chiang Rai	653
11	Chon Buri	161
12	Chumphon	1,014
13	Kalasin	103
14	Kamphaeng Phet	78
15	Kanchanaburi	2,085
16	Khon Kaen	132
17	Krabi	575
18	Lampang	941
19	Lamphun	351
20	Loei	824
21	Lop Buri	69
22	Mae Hong Son	2,280
23	Maha Sarakham	36
24	Mukdahan	79
25	Nakhon Nayok	74
26	Nakhon Pathom	3
27	Nakhon Phanom	75
28	Nakhon Ratchasima	360
29	Nakhon Sawan	464
30	Nakhon Si Thammarat	1,784
31	Nan	1,529
32	Narathiwat	287
33	Nong Bua Lam Phu	43
34	Nong Khai	205
35	Nonthaburi	1
36	Pathum Thani	1
37	Pattani	95
38	Phangnga	745
39	Phatthalung	486
40	Phayao	255

Map ID	Province	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
41	Phetchabun	417
42	Phetchaburi	95
43	Phichit	18
44	Phitsanulok	836
45	Phra Nakhon Si Ayutthaya	2
46	Phrae	600
47	Phuket	19
48	Prachin Buri	115
49	Prachuap Khiri Khan	384
50	Ranong	753
51	Ratchaburi	115
52	Rayong	110
53	Roi Et	88
54	Sa Kaeo	458
55	Sakon Nakhon	120
56	Samut Prakan	1
57	Samut Sakhon	0
58	Samut Songkhram	0
59	Saraburi	49
60	Satun	432
61	Si Sa Ket	166
62	Sing Buri	1
63	Songkhla	1,346
64	Sukhothai	346
65	Suphan Buri	33
66	Surat Thani	1,402
67	Surin	147
68	Tak	4,553
69	Trang	1,769
70	Trat	286
71	Ubon Ratchathani	274
72	Udon Thani	162
73	Uthai Thani	935
74	Uttaradit	478
75	Yala	715
76	Yasothon	50
	Thailand	**38,132**

7.2 FACTORS FOR NATIONAL CIRCUMSTANCES

This section illustrates seven key factors that are often used to explain patterns of deforestation across Thailand. All factors are subsets of the regional factors presented in the regional Atlas (section 3.2). Maps of elevation, roads, settlements (populated places), climate zones, soil nutrient availability, protected areas and rural population growth are shown in Figures T-6-12.

7.2.1 Elevation

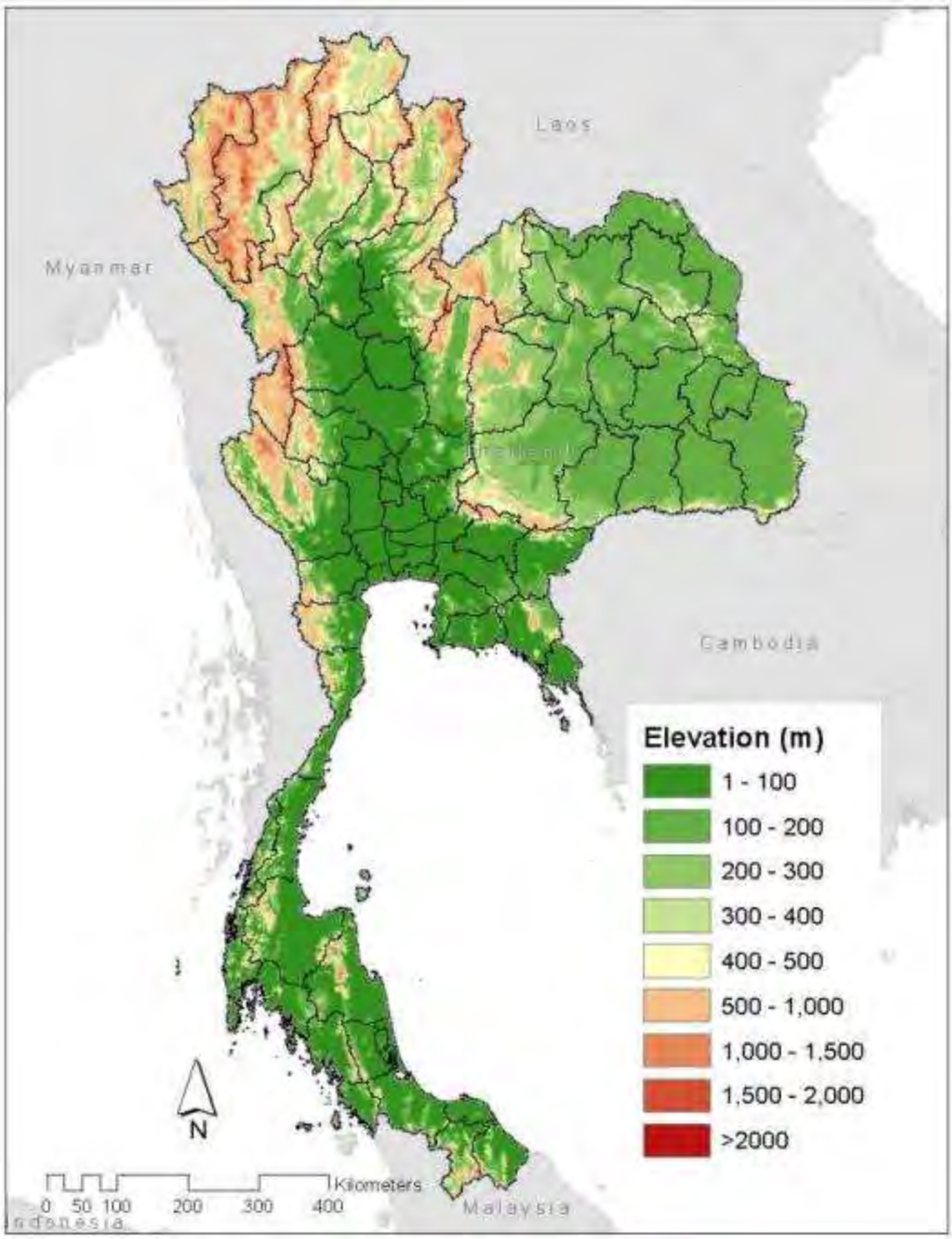


Figure T-6. Elevation across Thailand.

7.2.2 Roads

Figure T-7. Location of roads across Thailand.

7.2.3 Settlements

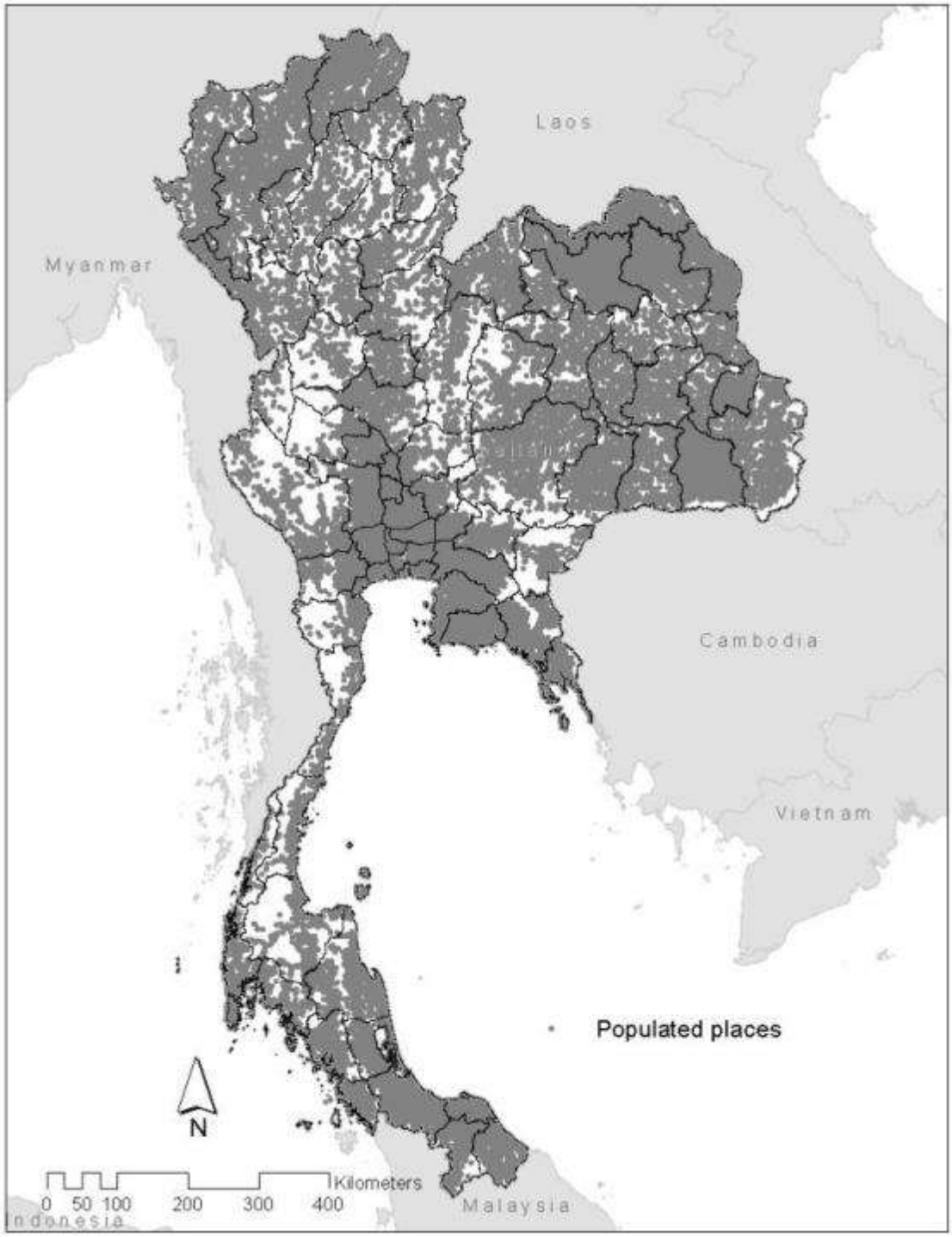


Figure T-8. Map of all settlements (populated places) across Thailand.

7.2.4 Climate

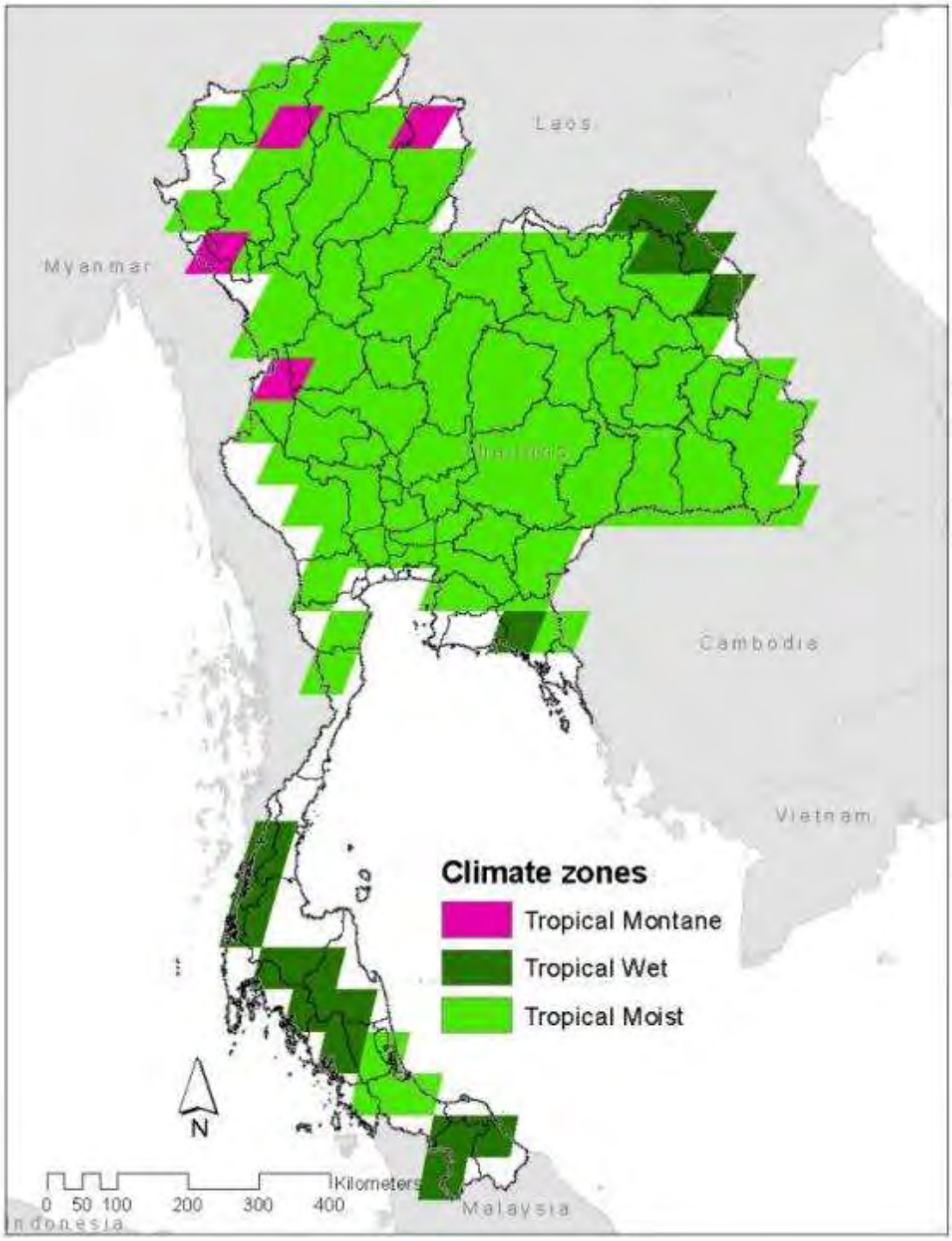


Figure T-9. Map of Climate zones across Thailand.

7.2.5 Soil nutrient availability

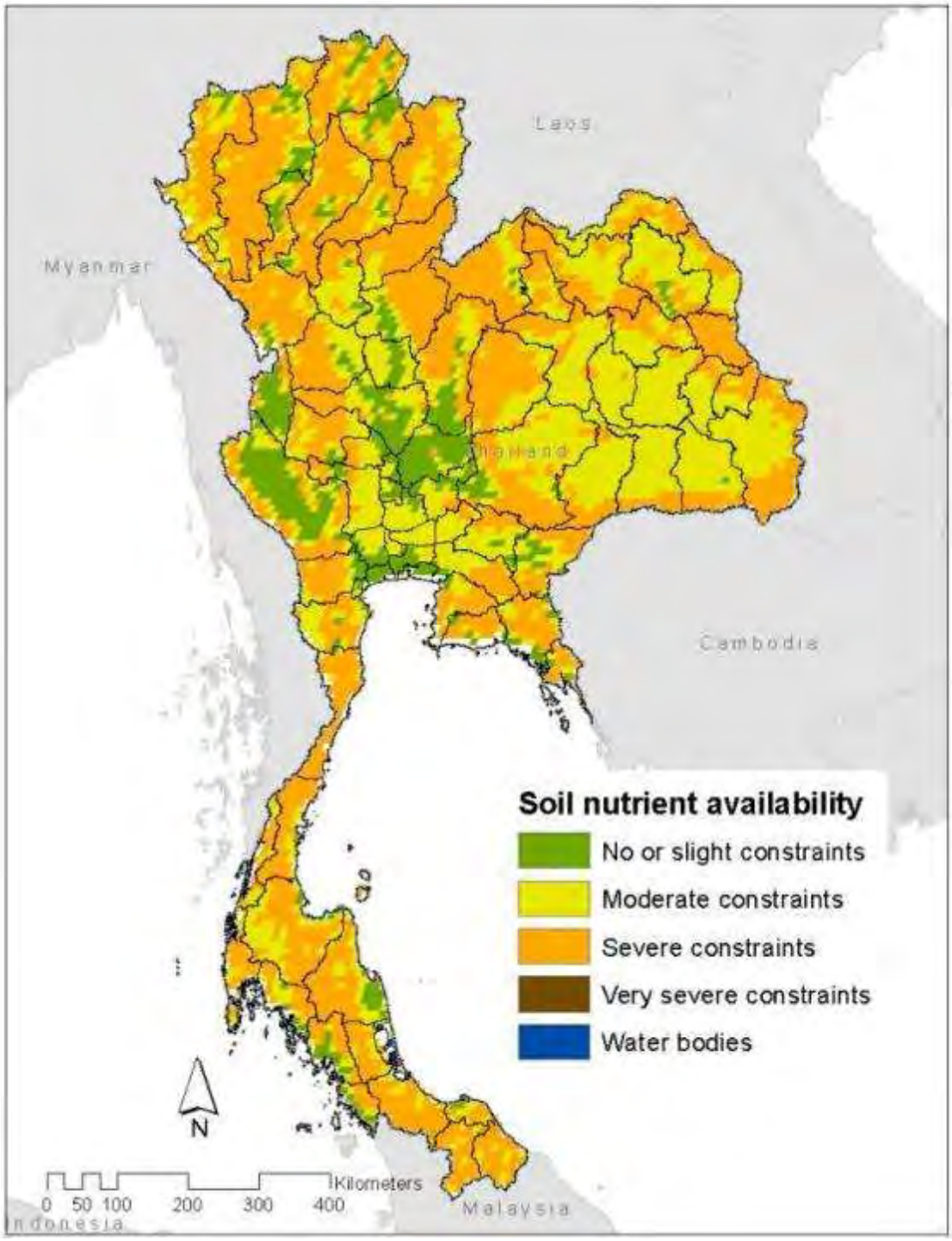


Figure T-10.Map of areas with soil nutrient availability across Thailand.

7.2.6 Rural population growth

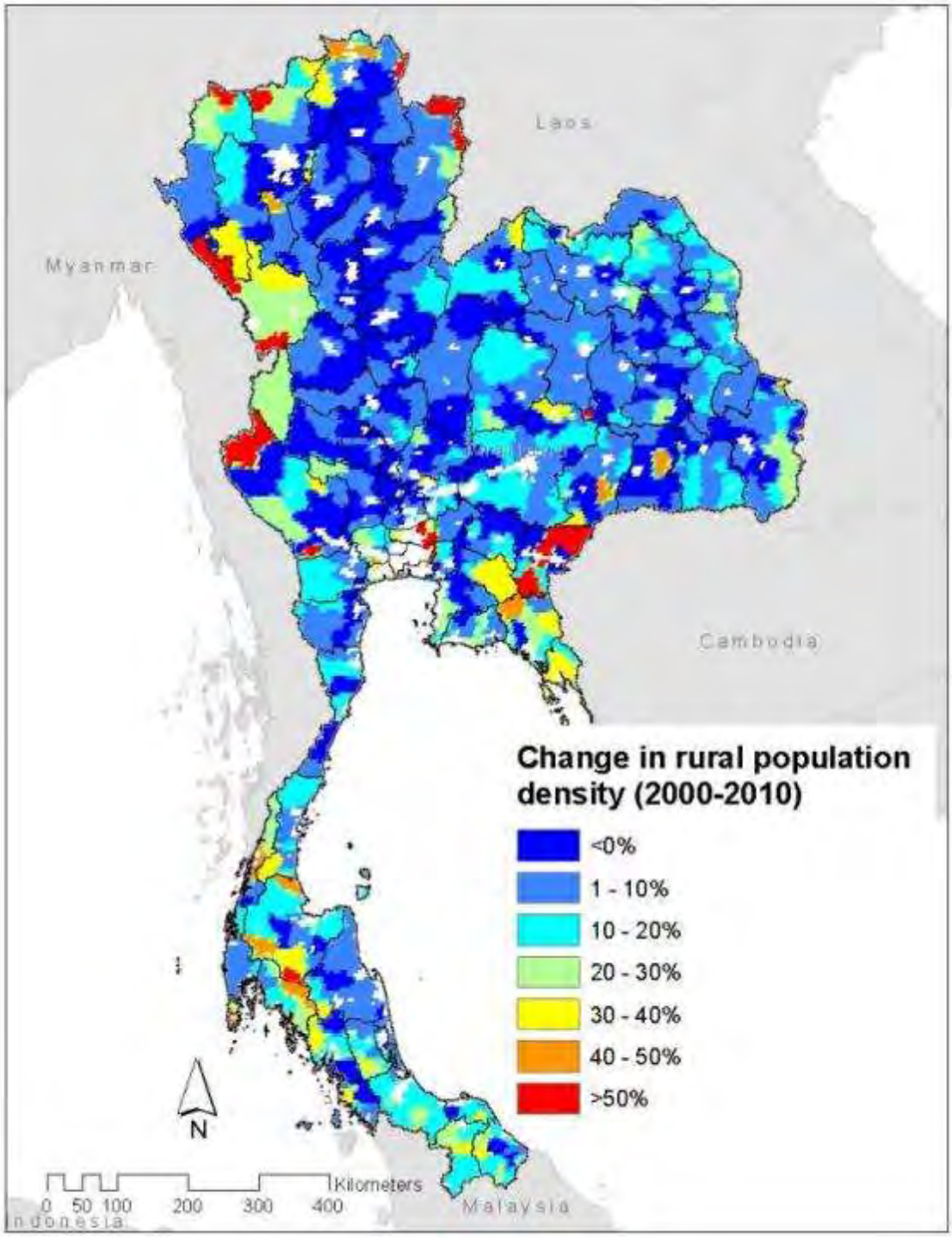


Figure T-11. Rural population growth shown as percent population density.

7.2.7 Protected areas

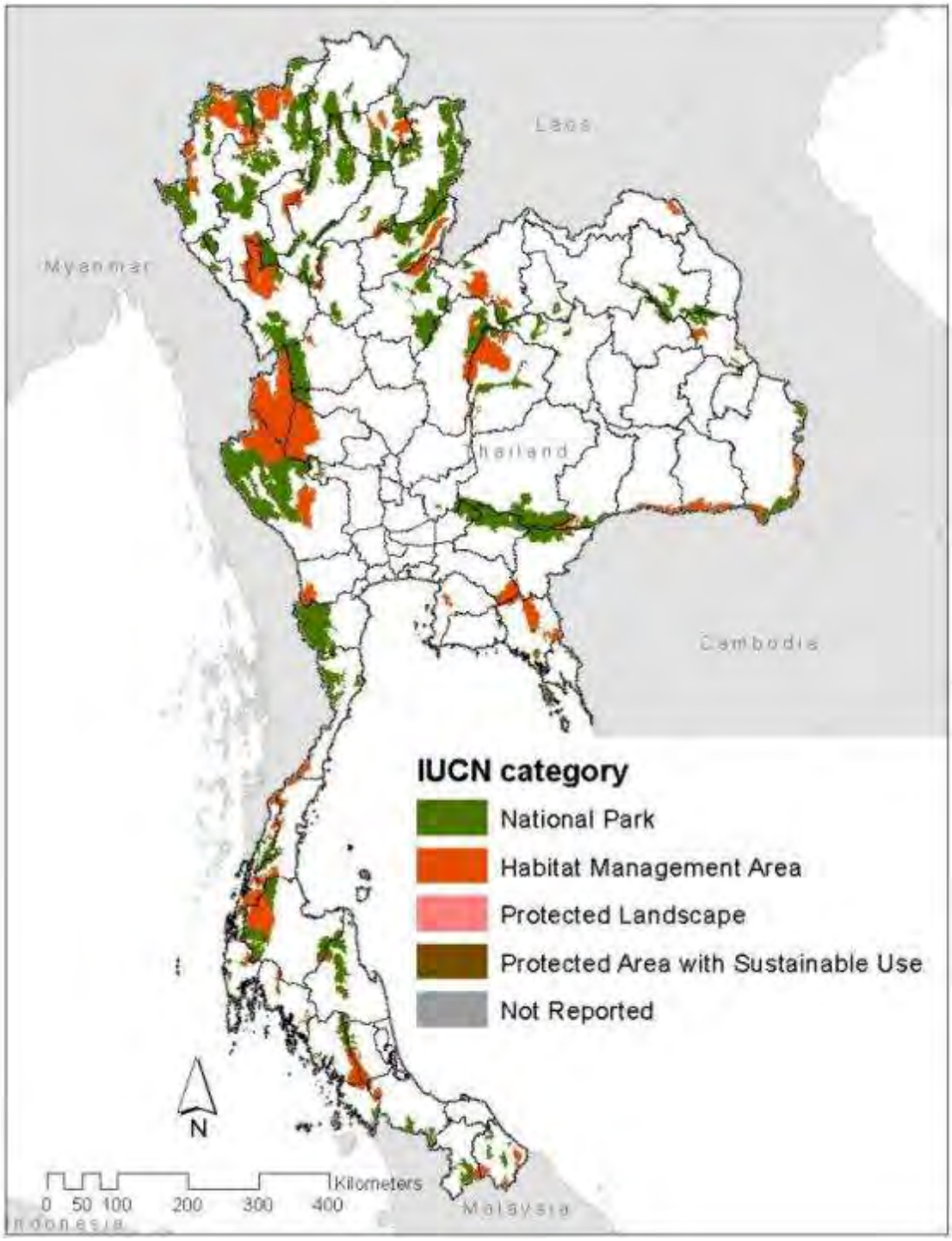


Figure T-12. Map of Protected Areas by IUCN category.

7.3 FOREST THREATS

This section presents spatial overlays of different factors over the 2000 map of forest cover (defined as at least 25% tree cover from MODIS VCF data) to illustrate possible threats to the forest in Thailand in terms of potential for future deforestation. These spatial overlays present examples of how different threat for forests can be mapped with country-specific data. These examples use coarse resolution global datasets, and more detailed analysis can be done using country/province-specific data for key factors of interest.

7.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forest to other land uses depends on the amount carbon stored in the forest. Understanding where forests with high carbon stocks, and thus potential for high emissions from deforestation, are located within Thailand could provide input to decisions regarding land use planning in the country.

Figure T-13 illustrates the distribution of carbon stocks categories across forests in Thailand. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}).

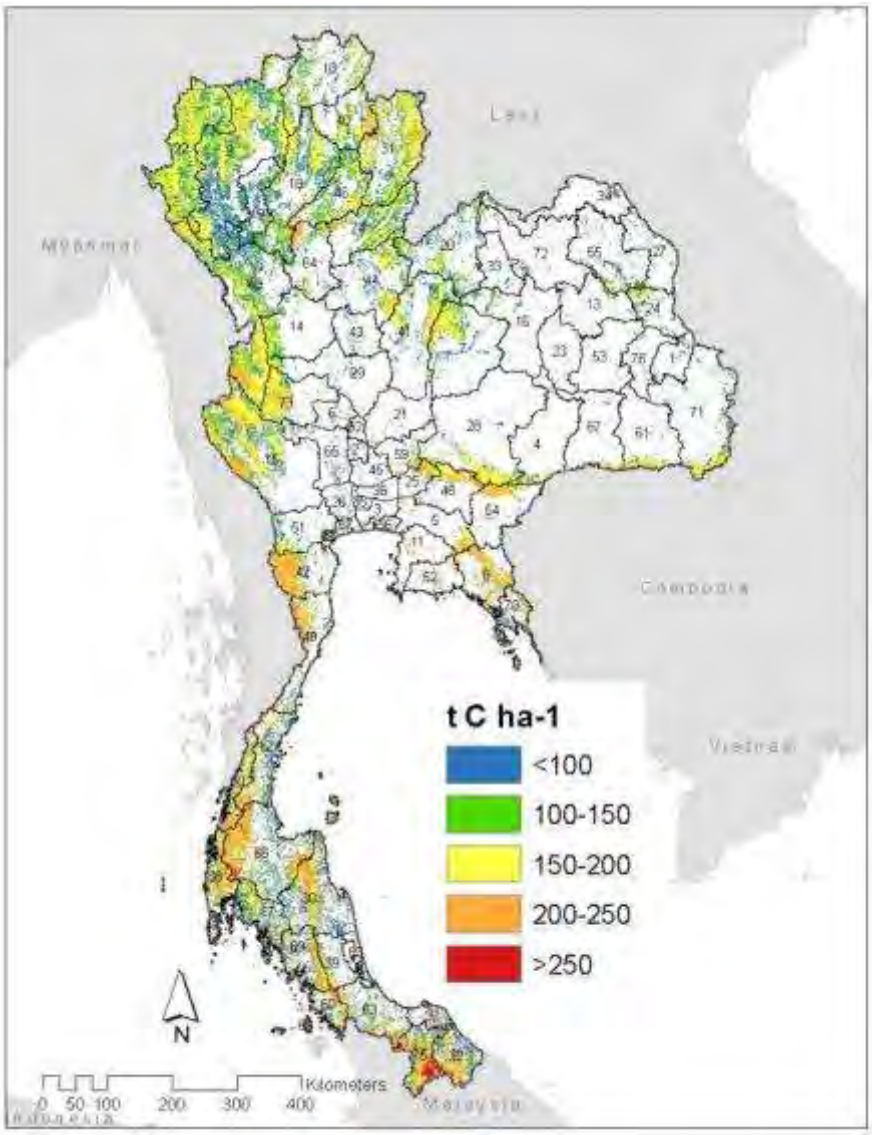


Figure T-13. Forest carbon stocks for forest cover in 2000 across Thailand.

Table T-13 reports the percent forests per carbon stock category for provinces in Thailand. The largest part of the forests was classified in MEDIUM HIGH carbon category (34%), followed by the LOW carbon category (30%) and the least area of the forest was classified in VERY HIGH carbon category (1%).

Table T-6. Sub-national estimates as percent forest cover per carbon stock category. Carbon stocks categories are defined as LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150-200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (< 250 t C ha^{-1})

Map ID	Provinces	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
1	Amnat Charoen	32	0	0	3	9	88
2	Ang Thong	5	0	0	0	1	99
3	Bangkok Metropolis	1	0	0	0	0	100
4	Buri Ram	65	0	4	50	19	27
5	Chachoengsao	73	0	42	40	3	15
6	Chai Nat	12	0	0	0	4	96
7	Chaiyaphum	293	0	8	47	15	30
8	Chanthaburi	217	2	52	21	9	16
9	Chiang Mai	1,494	0	2	41	21	36
10	Chiang Rai	392	0	3	44	22	32
11	Chon Buri	28	0	24	24	15	37
12	Chumphon	264	2	24	22	16	36
13	Kalasin	30	0	2	19	10	69
14	Kamphaeng Phet	173	0	6	42	29	24
15	Kanchanaburi	926	0	20	43	19	17
16	Khon Kaen	69	0	0	10	29	60
17	Krabi	296	0	14	18	18	50
18	Lampang	712	0	5	37	24	33
19	Lamphun	206	0	0	12	21	67
20	Loei	289	0	2	26	24	48
21	Lop Buri	15	0	0	0	5	95
22	Mae Hong Son	1,149	0	8	55	22	14
23	Maha Sarakham	2	0	0	0	0	100
24	Mukdahan	82	0	5	30	14	50
25	Nakhon Nayok	64	0	49	38	7	6
26	Nakhon Pathom	11	0	0	0	1	99
27	Nakhon Phanom	47	0	0	9	6	85
28	Nakhon Ratchasima	229	0	13	59	7	20
29	Nakhon Sawan	73	0	3	28	26	42
30	Nakhon Si Thammarat	455	1	30	13	12	43
31	Nan	798	0	14	50	19	17
32	Narathiwat	258	11	36	16	11	27
33	Nong Bua Lam Phu	22	0	0	0	1	99
34	Nong Khai	43	0	3	6	10	81
35	Nonthaburi	1	0	0	0	0	100
36	Pathum Thani	3	0	0	0	0	100
37	Pattani	48	0	6	5	16	73
38	Phangnga	267	4	36	19	15	28

Map ID	Provinces	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
39	Phatthalung	86	1	28	23	16	33
40	Phayao	292	0	13	49	15	23
41	Phetchabun	318	0	7	39	18	36
42	Phetchaburi	307	1	56	28	6	10
43	Phichit	20	0	0	0	4	96
44	Phitsanulok	338	0	9	37	18	36
45	Phra Nakhon Si Ayutthaya	11	0	0	0	0	100
46	Phrae	375	0	8	41	30	22
47	Phuket	22	0	4	17	13	65
48	Prachin Buri	130	0	32	51	8	10
49	Prachuap Khiri Khan	239	2	54	16	11	16
50	Ranong	216	2	40	26	12	20
51	Ratchaburi	100	0	11	40	16	34
52	Rayong	33	0	32	12	26	29
53	Roi Et	14	0	0	5	16	79
54	Sa Kaeo	124	0	53	31	4	11
55	Sakon Nakhon	105	0	3	18	11	69
56	Samut Prakan	3	0	0	0	0	100
57	Samut Sakhon	8	0	0	0	3	97
58	Samut Songkhram	19	0	15	11	24	50
59	Saraburi	40	0	31	13	24	32
60	Satun	150	2	28	16	12	43
61	Si Sa Ket	87	0	22	52	7	20
62	Sing Buri	2	0	0	0	2	98
63	Songkhla	221	5	28	14	17	36
64	Sukhothai	170	0	30	20	23	27
65	Suphan Buri	48	0	0	11	9	80
66	Surat Thani	656	5	38	17	11	29
67	Surin	50	0	13	47	13	28
68	Tak	1,142	0	14	41	19	26
69	Trang	245	0	32	12	10	45
70	Trat	123	2	23	10	18	47
71	Ubon Ratchathani	190	0	16	35	8	41
72	Udon Thani	60	0	2	19	12	67
73	Uthai Thani	288	0	25	57	12	7
74	Uttaradit	395	0	11	35	26	27
75	Yala	331	22	37	17	14	10
76	Yasothon	12	0	0	2	2	96
	Thailand	**16,114**	**1**	**17**	**34**	**17**	**30**

7.3.2 Analysis #2: Forest and agriculture suitability

Most forests are cleared for agriculture (small or large scale), and soil nutrient availability is a key factor that can be used to predict future threat to the forest. Figure T-14 illustrates the potential suitability for agriculture across forest areas in 2000 based on soil nutrient availability. Forests with slight to moderate constraints based on soil nutrient availability were considered more suitable, while forests with severe and very severe constraints were considered not suitable for agriculture.

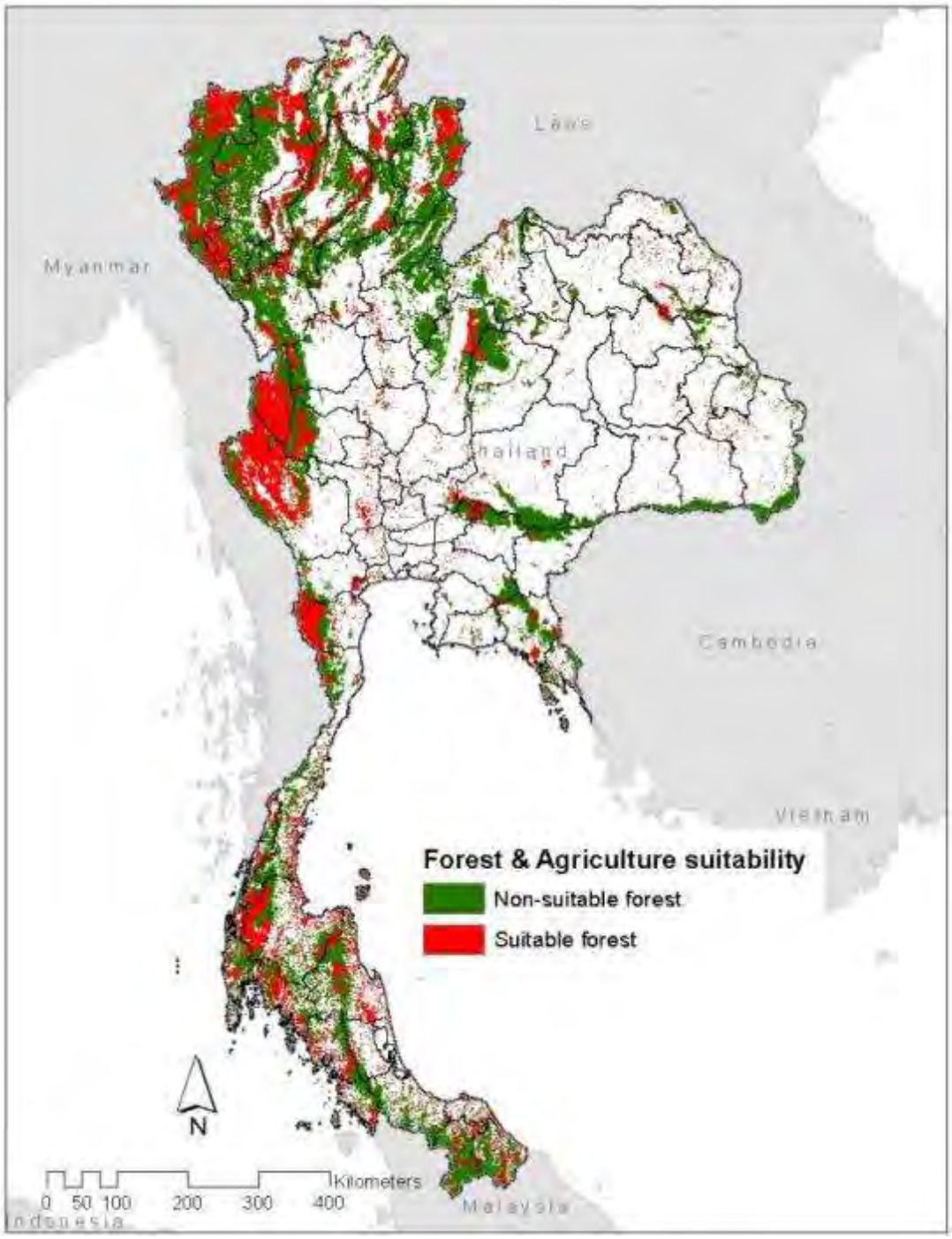


Figure T-14. Spatial overlay of forests areas in 2000 with no or slight to moderate constraints (red) and with high and very high (green) constraints on soil nutrient availability for Thailand.

Figure T-15 illustrates the distribution of the carbon stock categories across forests with potential suitability for agriculture use in Thailand.

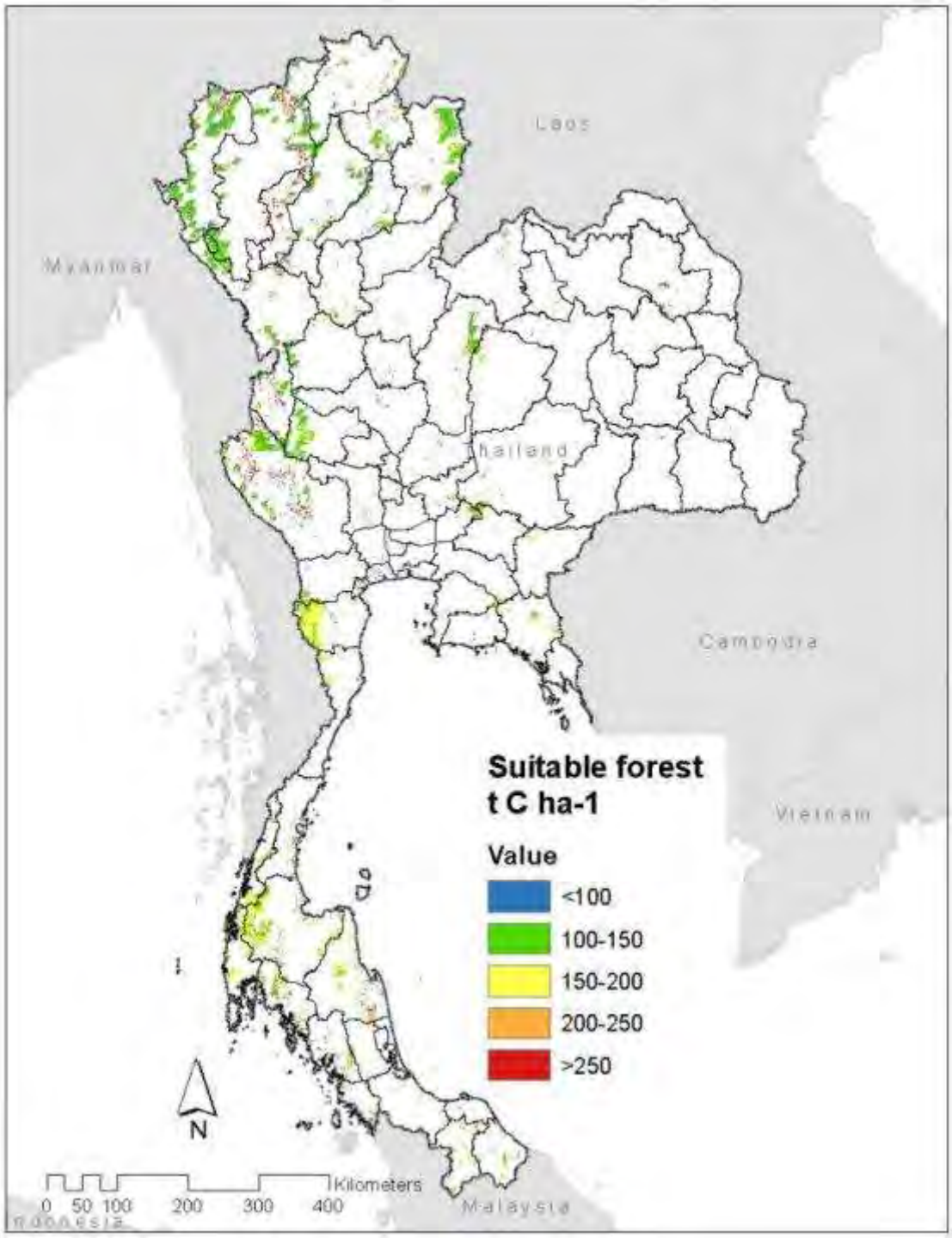


Figure T-15. Spatial overlay of forest lands suitable for agriculture and their respective forest carbon stocks.

7.3.3 Analysis #3: Forest and road network

Forests close to roads are more likely to be deforested or disturbed than forests further away from roads. Using the assumption that forests within 5km from the roads are more accessible, Figure T-16 illustrates accessibility of forests in Thailand based on this criterion. Figure T-17 illustrates the distribution of carbon stock categories across the more accessible forest, defined within the 5 km buffer zone around the roads.

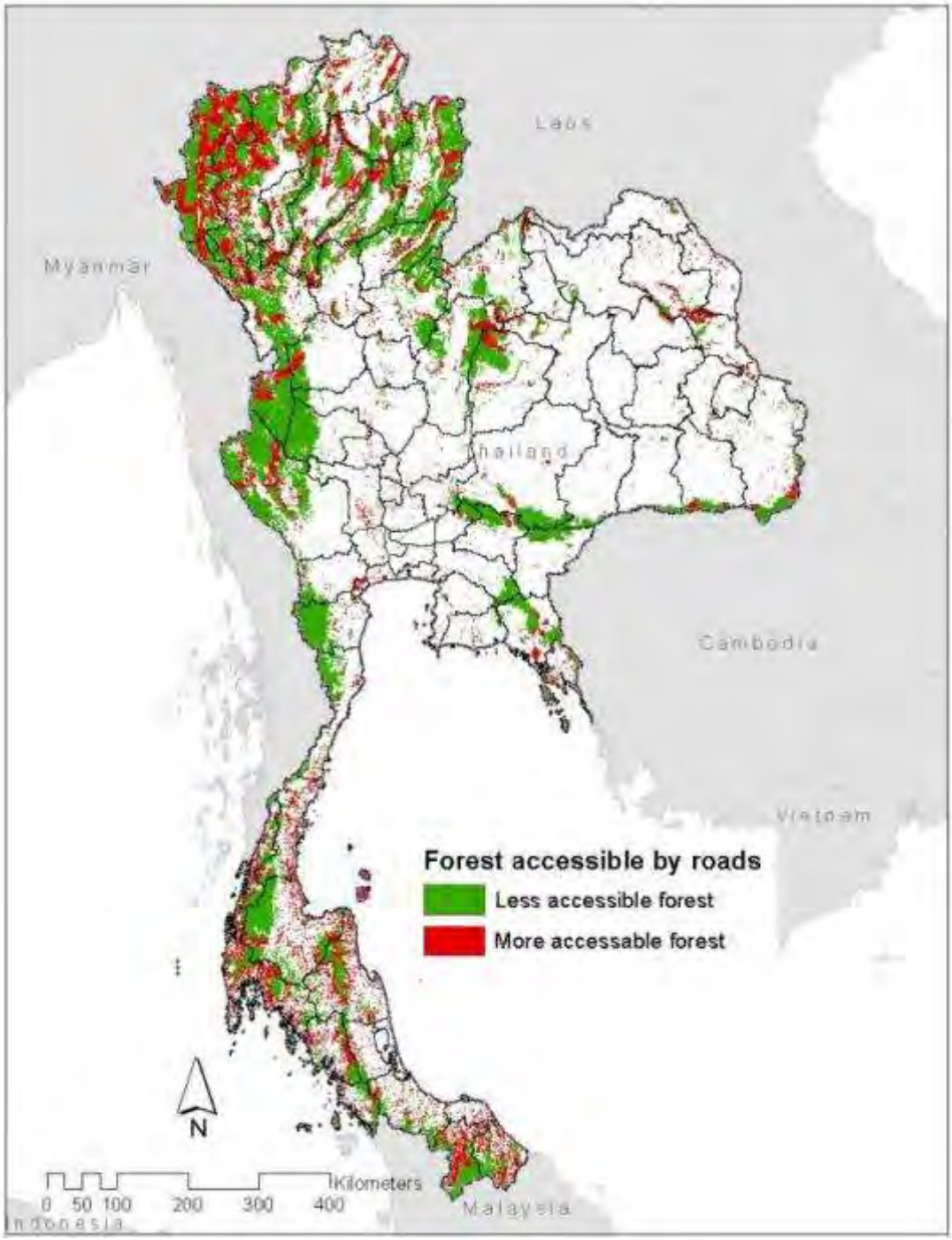


Figure T-16. Spatial overlay of forest cover in 2000 and 5 km buffer zone around road network in Thailand. More accessible forests are defined as forests within 5 km buffer zone and less accessible forests are defined as forests outside this zone.

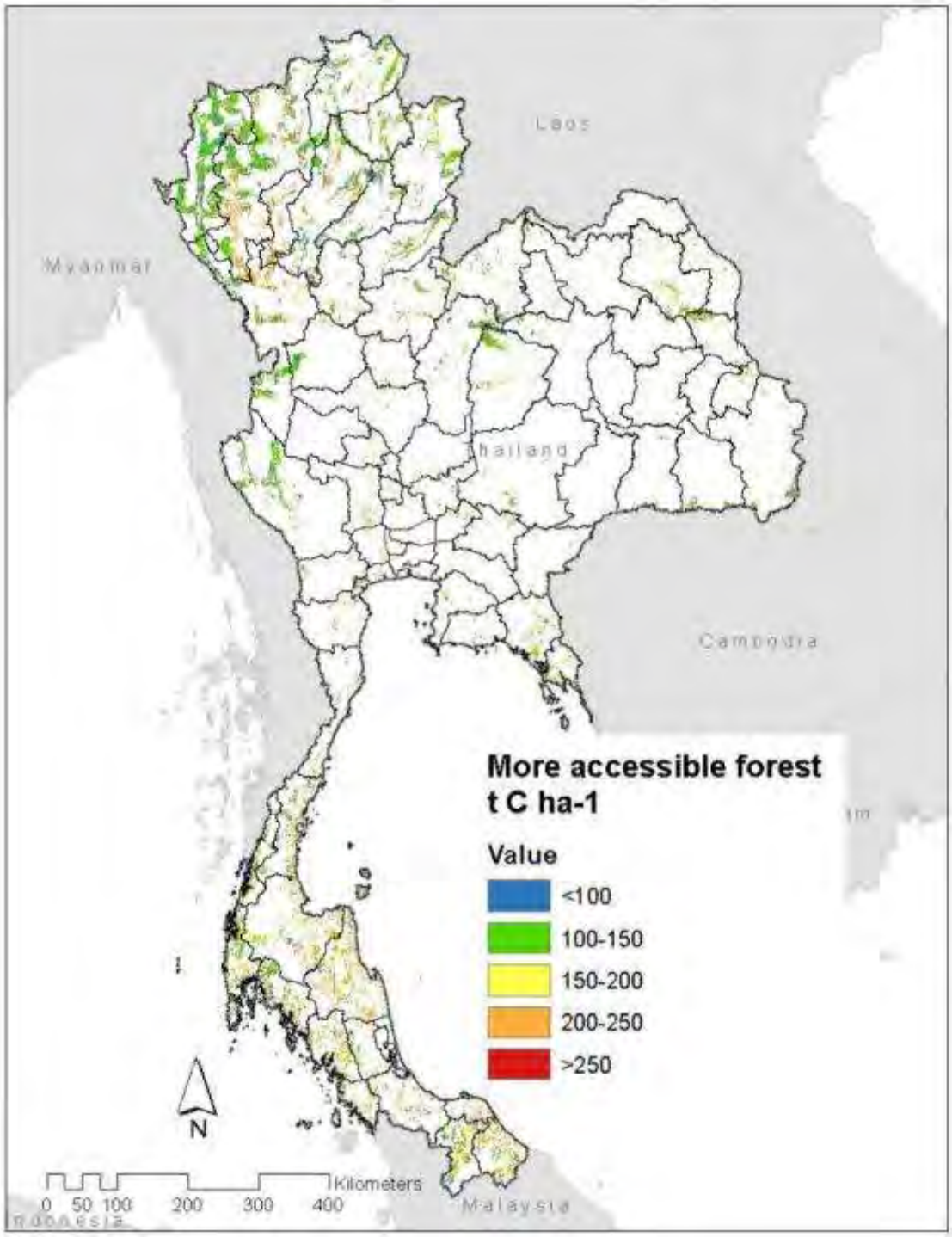


Figure T-17. Spatial overlay of more accessible forest (within 5 km buffer zone around roads) and carbon stocks.

7.3.4 Analysis #4: Forest and change in population

Increases in rural population can lead to increased potential threat to forests. Figure T-18 illustrates the change in population density in Thailand based on the Gridded Population of the World (GPWv3) data.[8] Based on GPWv3, rural population experienced a wide range of change across the country.

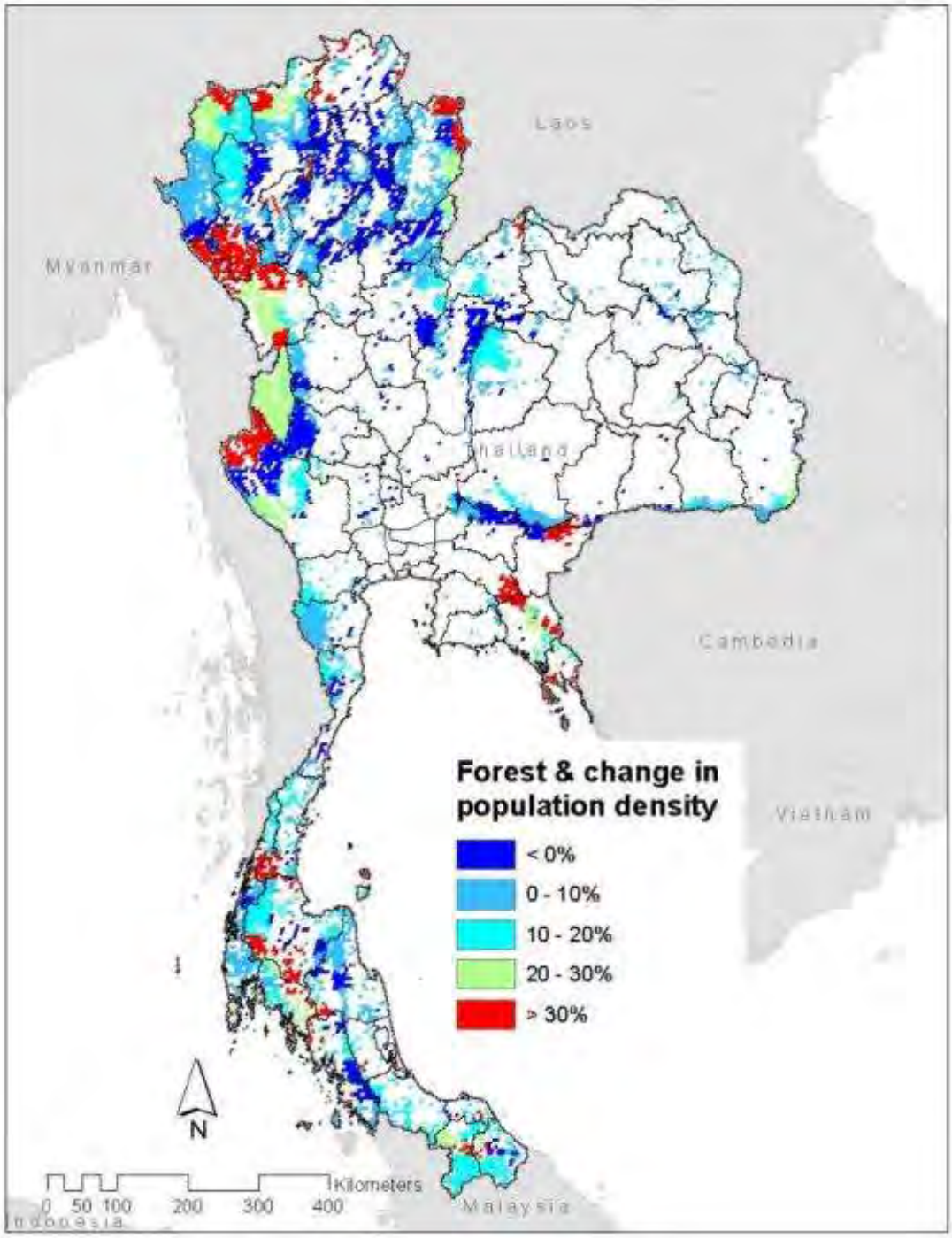


Figure T-18. Spatial overlay of forest cover and change in rural population density between 2000 and 2010

[8] This representation does not necessarily reflect the actual population growth data based on Thailand census data.

7.3.5 Analysis #5: Forest and elevation

In most cases deforestation occurs at low elevation, where people usually live. To illustrate the potential threat to forests based on elevation, Figure T-19 shows the forest across Thailand in three elevation categories: low (1-500m), medium (500-1,500m) and high (>1,500m). The forests in the north are located at medium elevation, while in the south, while the forests in the south are located mostly at low elevation. A very small portion of the total forest in Thailand is located at high elevation.

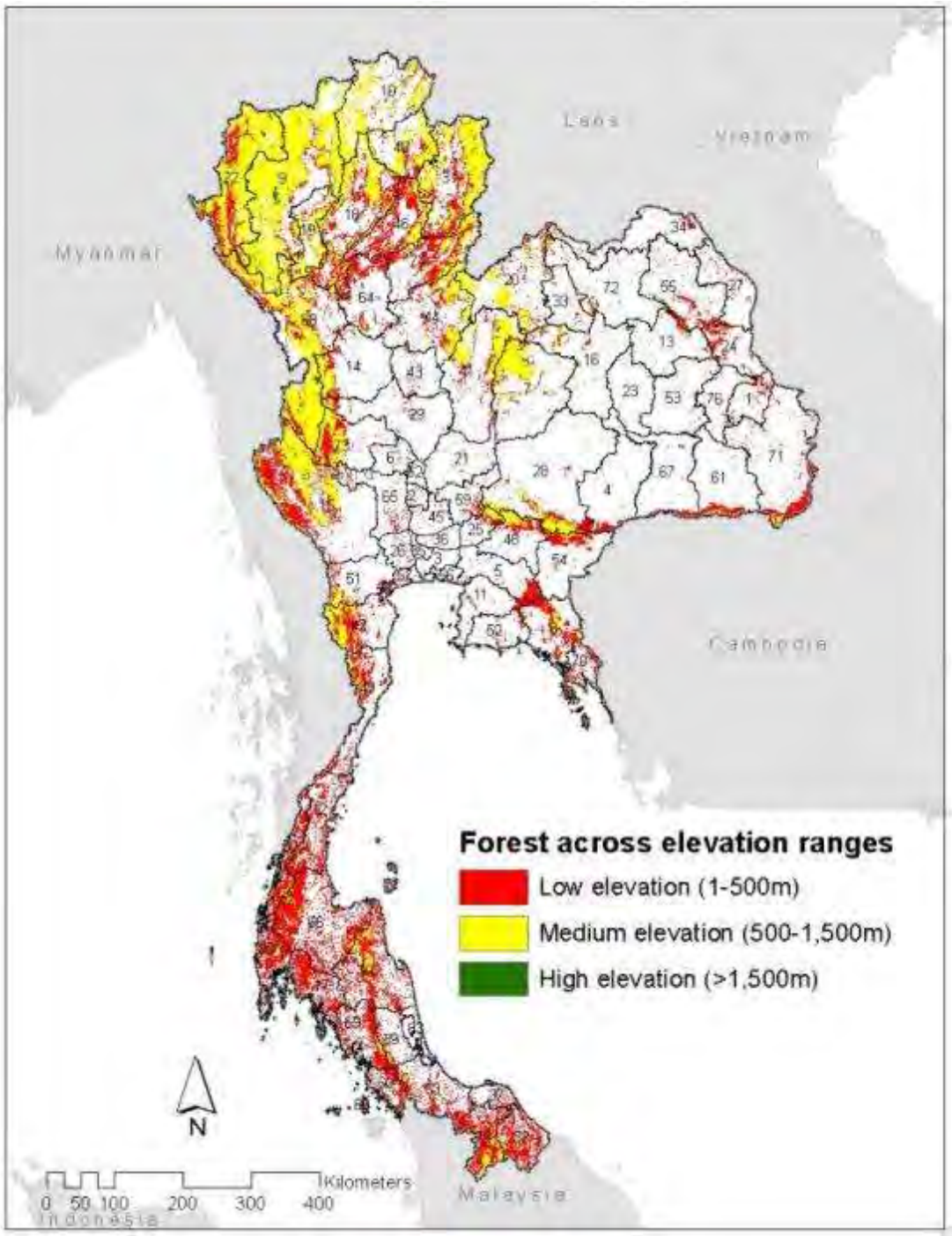


Figure T-19. Forest cover in Thailand for 2000 by elevation classes

8. VIETNAM

This section presents the same maps and statistics given in the South and Southeast Asia Atlas (Chapter 2) reported at the subnational level for Vietnam. These highlight key factors that should be considered for defining national circumstances, and illustrate forest threats based on roads, change in population density, elevation and suitability for agriculture based on nutrient availability.

8.1 NATIONAL STATISTICS RELATED TO REDD+

8.1.1 Forest cover

A forest cover map was extracted from 2000 MODIS VCF data presenting forest cover greater than 25% tree cover. Total forest area for Vietnam based on these data (Table V-1) differs from the forest area reported under the Regional Atlas Section 3.1 Table 1 due to differences in data and methods for calculating forest area at regional and national /subnational scales.

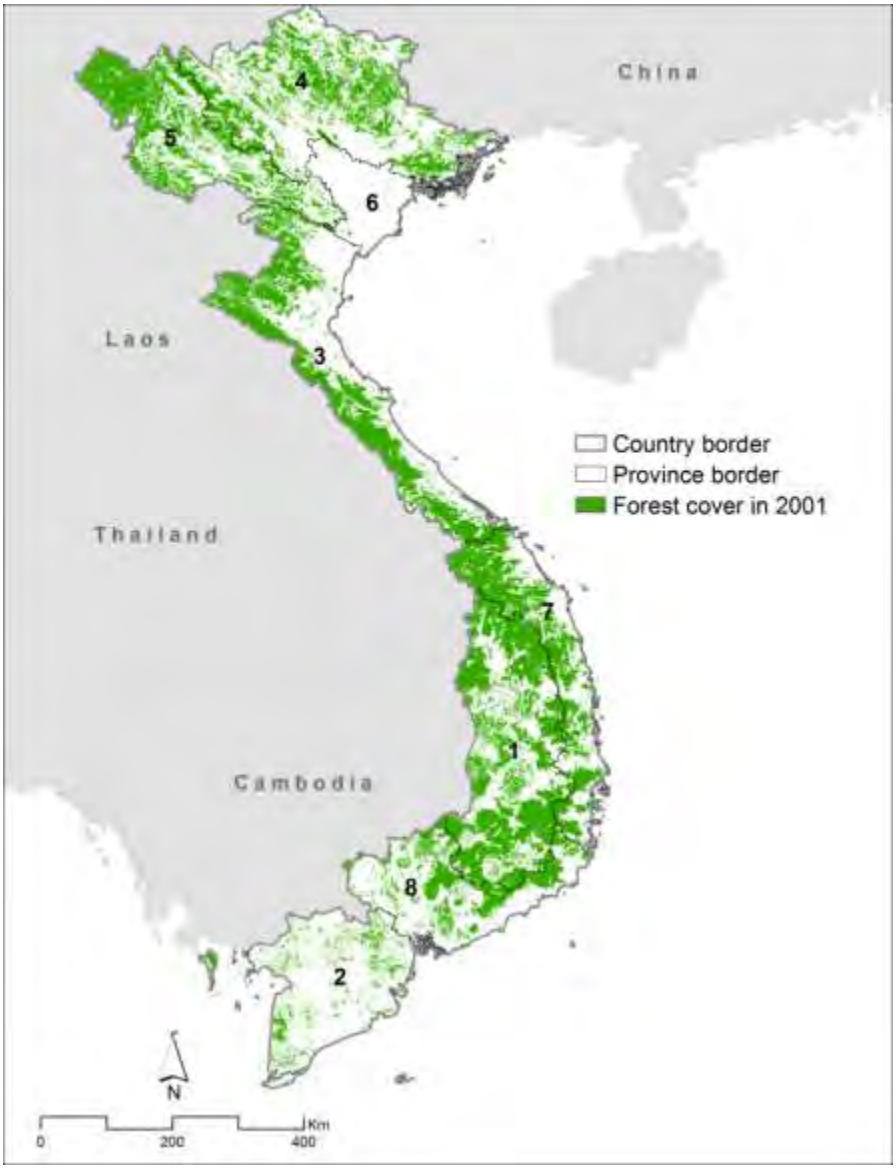


Figure V-1. Forest cover in 2000 across Vietnam. Forest cover is defined greater than 25% tree cover from MODIS VCF data. Provinces are labeled according to 'Map ID' information provided in Table V-1.

Figure V-1 shows the extent of forest cover in 2000 across the provinces in Vietnam and Table V-1 reports the forest coverage per province and percent of the province area covered by forest. According to spatial data, 42% of the total forest area was forested.

Central Highland province had the largest extent of forest cover (59%), while Red River Delta province had the least extent of forest cover (4%).

Table V-1. Province level estimates of forests and percent of province area in forest cover for 2000

Map ID	Province	Province Area (1000 ha)	Province Forest Cover (1000 ha)	Percent of Province Area in Forest Cover (%)
1	Central Highlands	5,480	3,230	59%
2	Mekong River Delta	4,020	591	15%
3	North Central Coast	5,113	2,536	50%
4	North East	6,398	2,409	38%
5	North West	3,745	2,063	55%
6	Red River Delta	1,480	65	4%
7	South Central Coast	3,235	1,755	54%
8	South East	3,477	1,214	35%
	Vietnam	**32,948**	**13,862**	**42%**

8.1.2 Forest cover in protected areas

Figure V-2 illustrates the forest area in protected areas and Table V-2 reports the actual forest area and percent forest in protected area per province. Vietnam has 16% of its forest protected.

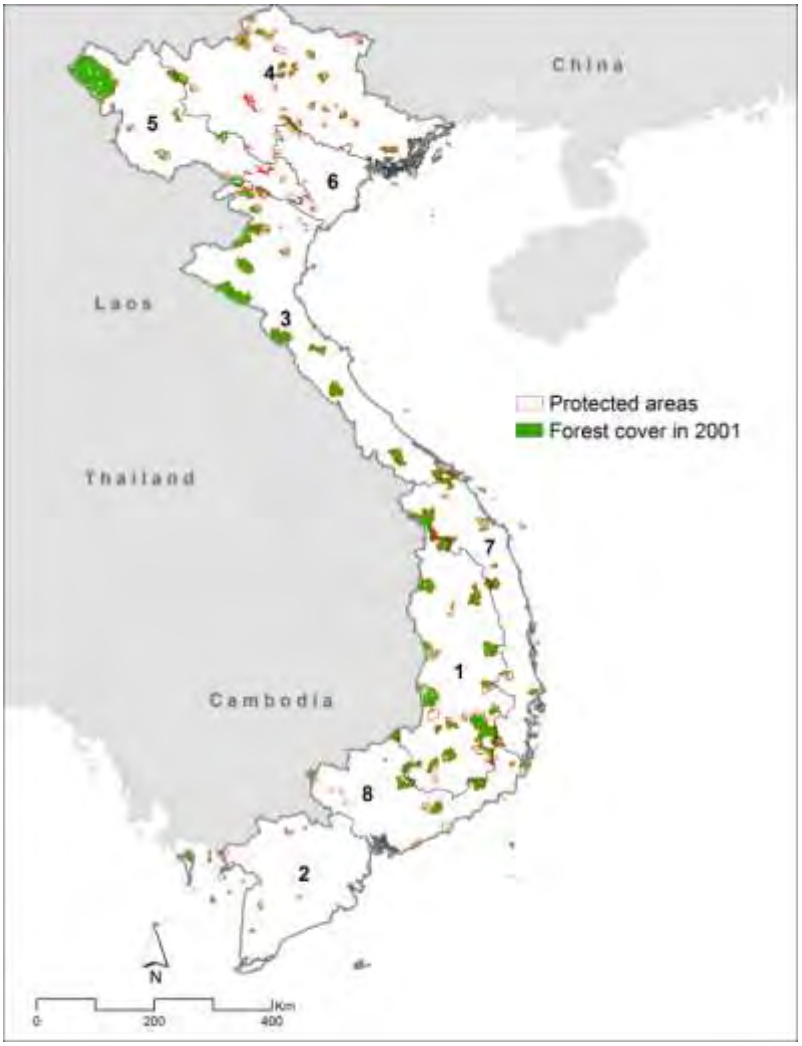


Figure V-2. Distribution of forest cover in 2000 within protected areas across Vietnam. Provinces are labeled according to 'Map ID' information provided in Table V-2.

The province with the highest percent forest in protected area is Red River Delta (39%), with 25,000 ha protected forest. The province with at least percent forest in protected area is Mekong River Delta (7%), with 44,000 ha protected forest.

Table V-2. Province-level estimates of forests in protected areas and percent protected forests of the total forest area in Vietnam

Map ID	Province	Forests in Protected Areas (1000 ha)	Percent of Total Forests in Protected Areas (%)
1	Central Highlands	617	19%
2	Mekong River Delta	44	7%
3	North Central Coast	497	20%
4	North East	224	9%
5	North West	400	19%
6	Red River Delta	25	39%
7	South Central Coast	232	13%
8	South East	190	16%
	Vietnam	**2,229**	**16%**

8.1.3 Gross Forest Cover Loss

The annual gross forest cover loss between 2000 and 2005 is shown in Figure V-3, with a summary of the actual values presented in Table V-3.

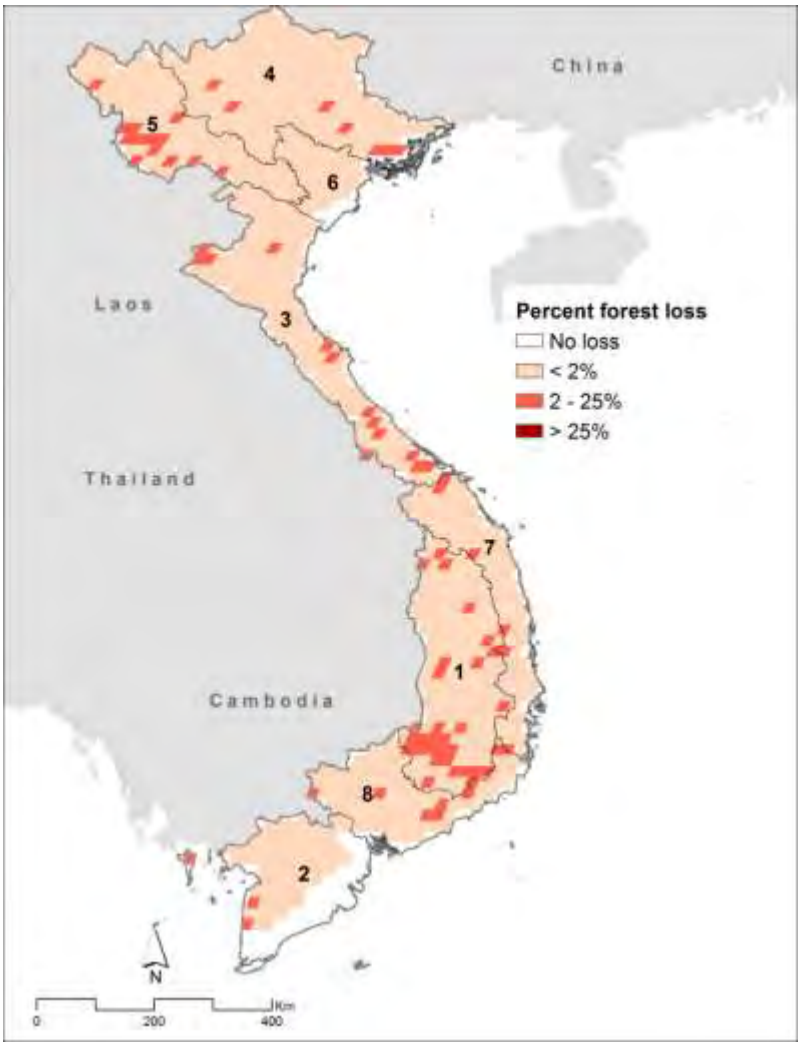


Figure V-3. Distribution of gross forest cover loss between 2000 and 2005 across Vietnam. Provinces are labeled according to 'Map ID' information provided in Table V-3.

Central Highlands, with 0.5 % is the province with highest gross forest loss expressed as a percent of the forests in 2000. South Central Coast and North Central Coast and Southern Highlands, with 0.3%, are the provinces with lowest gross forest loss expressed as percent of the forest cover in 2000

Table V-3. Province-level estimates of average annual gross forest cover loss between 2000 and 2005 expressed as hectares and percent of the forest cover in 2000

Map ID	Province	Average Annual Gross Loss in Forest Cover (ha yr-1)	Average Annual Loss as a Percent of Forest Cover in 2000 (%)
1	Central Highlands	15,674	0.5%
2	Mekong River Delta	2,653	0.4%
3	North Central Coast	7,756	0.3%
4	North East	9,786	0.4%
5	North West	8,278	0.4%
6	Red River Delta	242	0.4%
7	South Central Coast	4,741	0.3%
8	South East	5,234	0.4%
	Vietnam	**54,364**	**0.4%**

8.1.4 Biomass Carbon Stocks

Figure V-4 illustrates the distribution of the biomass carbon stocks according to Saatchi et al. (2011) clipped to the boundary of Vietnam.

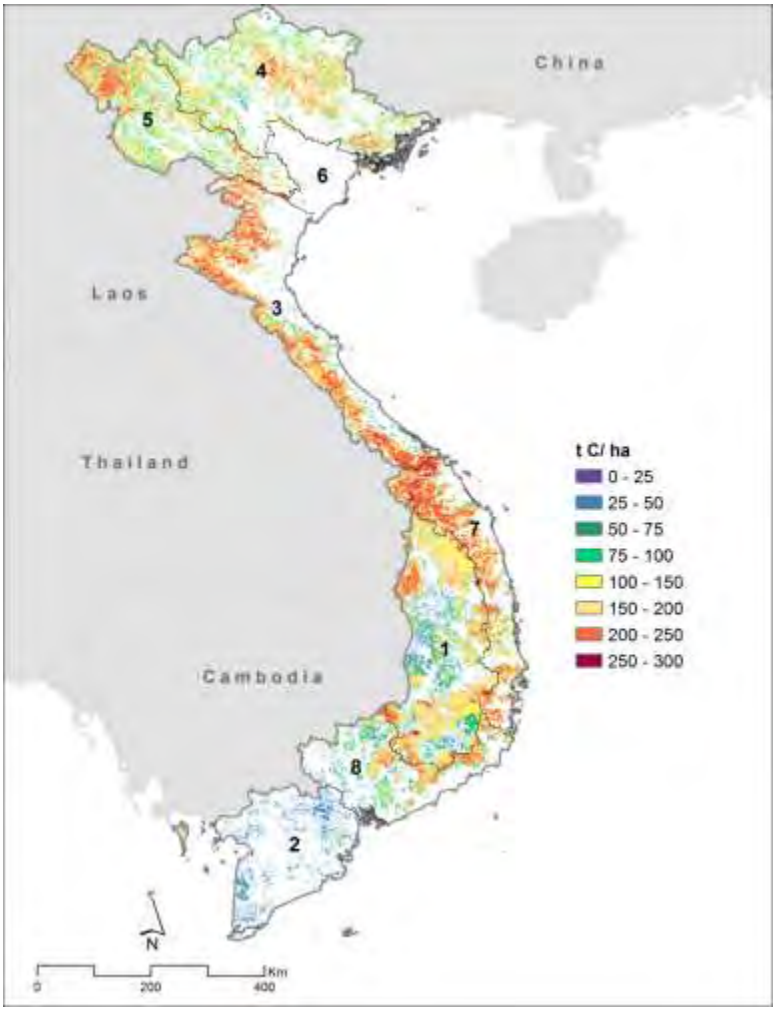


Figure V-4. Distribution of above and belowground forest biomass carbon stocks across Vietnam. Provinces are labeled according to 'Map ID' information provided in Table V-4.

The forests in South Central Coast province were with highest area weighted carbon stocks (182 t C ha^{-1}), while forests in Mekong River Delta province were with the lowest area weighted carbon stocks (43 t C ha^{-1}). The total forest carbon stock for the forest in 2000 was estimated at 2.080 Million t C, with Central Highlands and North Central Coast province contributing the most with 469 and 454 Million t C, respectfully. Red River Delta province contributed to the total forest carbon stocks with 8 Million t C.

Table 4. Province-level estimates of above and belowground forest biomass carbon stocks expressed as area weighted average (t C ha^{-1}) and total carbon (t C)

Map ID	Province	Area Weighted Forest Carbon Stocks (t C ha^{-1})	Total Forest Carbon Stocks (Million t C)
1	Central Highlands	145	469
2	Mekong River Delta	43	25
3	North Central Coast	179	454
4	North East	137	331
5	North West	151	312
6	Red River Delta	122	8
7	South Central Coast	182	320
8	South East	132	160

	Vietnam	127	2,080

8.1.5 Carbon emissions from deforestation

Annual carbon emissions from deforestation between 2000 and 2005 for Vietnam are shown in Figure V-5. Table V-5 reports the annual emissions from deforestation per province.

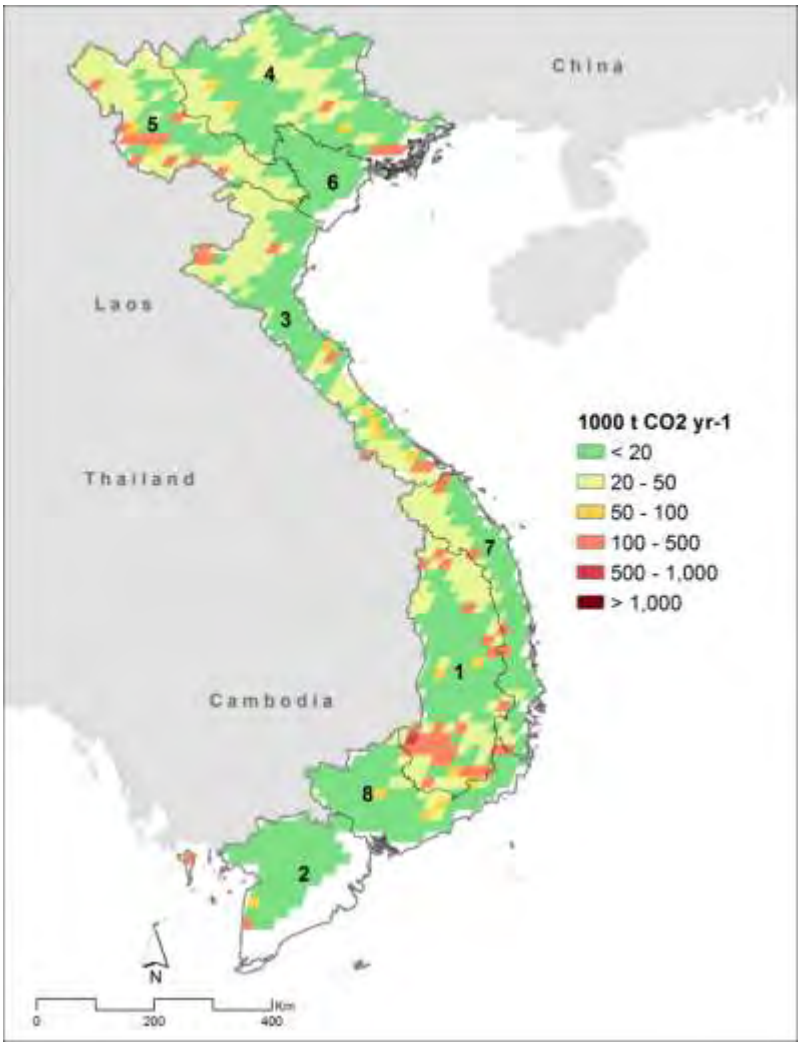


Figure V-5. Annual carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005 for Vietnam. Provinces are labeled according to 'Map ID' information found in Table V-5.

Total emissions from deforestation for Vietnam were 23,589,000 t CO_2 yr^{-1}. Central Highlands province (7,941,000 t CO_2 yr^{-1}) was found to have the highest annual CO_2 emissions from deforestation, followed by North Central Coast (3,806,000 t CO_2 yr^{-1}). Red River Delta province, with 68,000 t CO_2 yr^{-1} was found to have lowest annual CO_2 emissions from deforestation between 2000 and 2005.

Table V-5. Province-level estimates of carbon emissions (t CO_2 yr^{-1}) from deforestation 2000-2005

Map ID	Province	Annual Emissions from Deforestation (1000 t CO_2 yr^{-1})
1	Central Highlands	7,781
2	Mekong River Delta	533
3	North Central Coast	3,747
4	North East	3,606
5	North West	3,667
6	Red River Delta	58
7	South Central Coast	2,461

8	South East	1,734
	Vietnam	23,587

8.2 FACTORS FOR NATIONAL CIRCUMSTANCES

This section illustrates seven key factors that are often used to explain patterns of deforestation across Vietnam. All factors are subsets of the regional factors presented in the regional Atlas (section 3.2). Maps of elevation, roads, settlements (populated places), climate zones, soil nutrient availability, protected areas and rural population growth are shown in Figures V-6-12.

8.2.1 Elevation

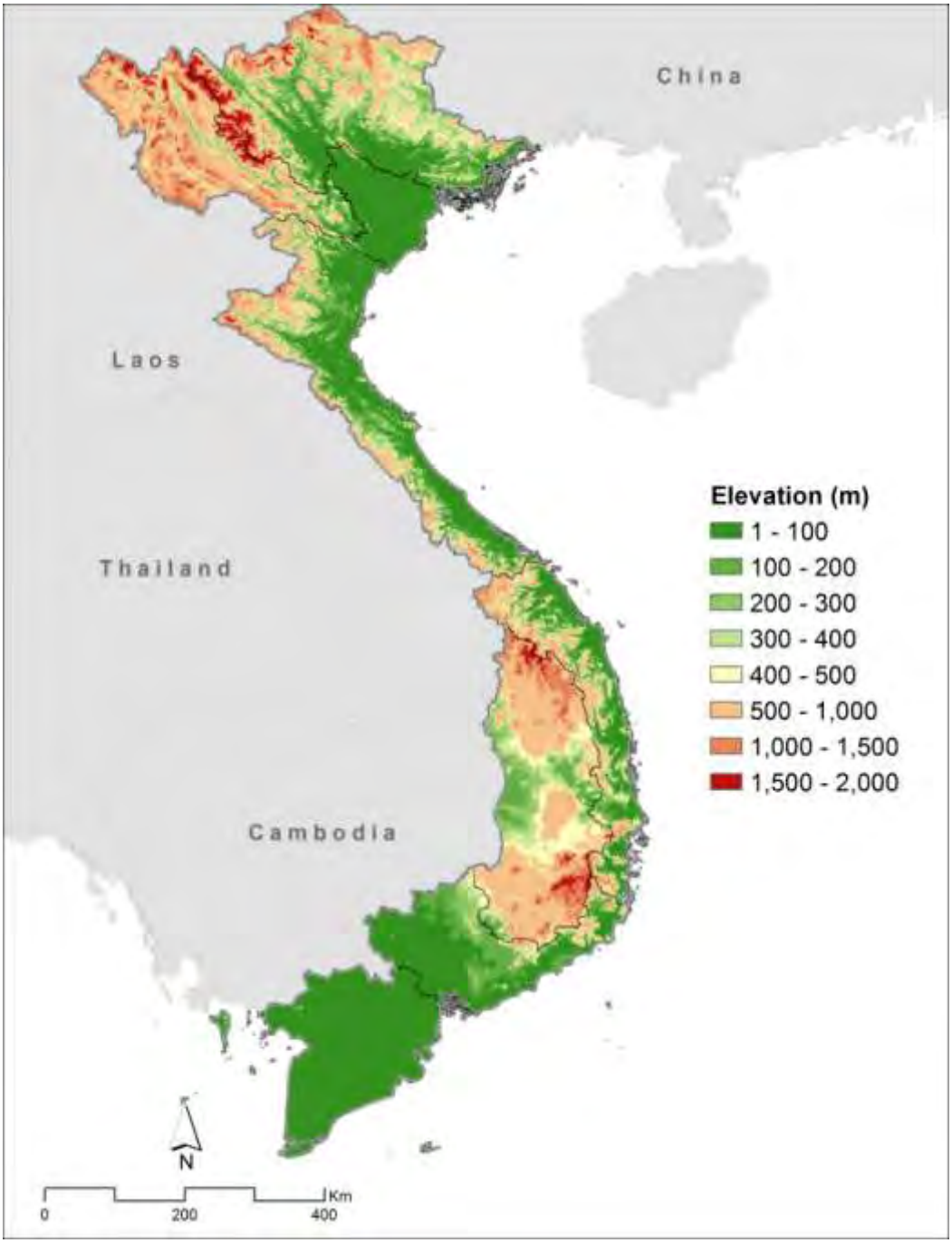


Figure V-6. Elevation across Vietnam.

8.2.2 Roads

Figure V-7. Location of roads across Vietnam.

8.2.3 Settlements

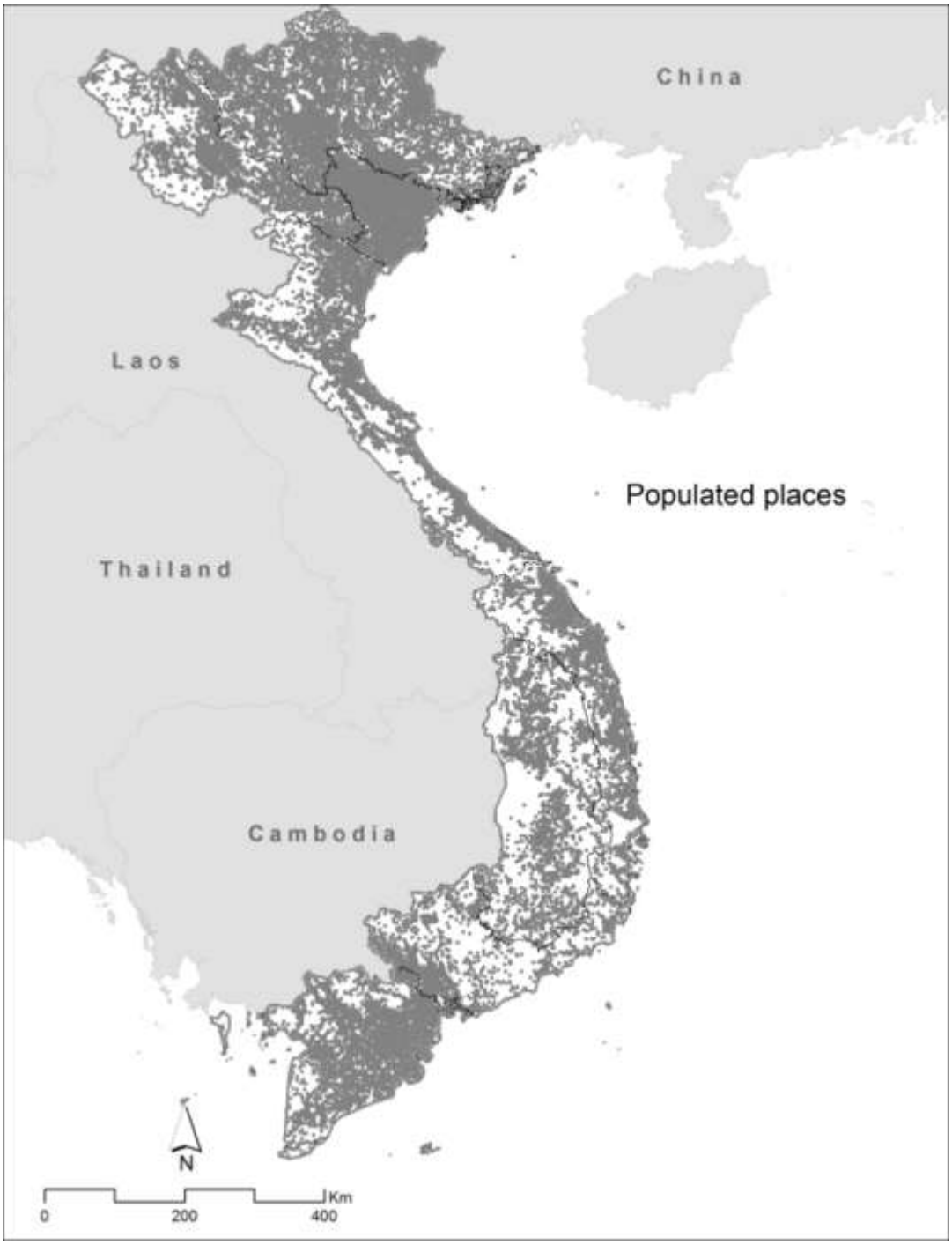


Figure V-8. Map of all settlements (populated places) across Vietnam.

8.2.4 Climate

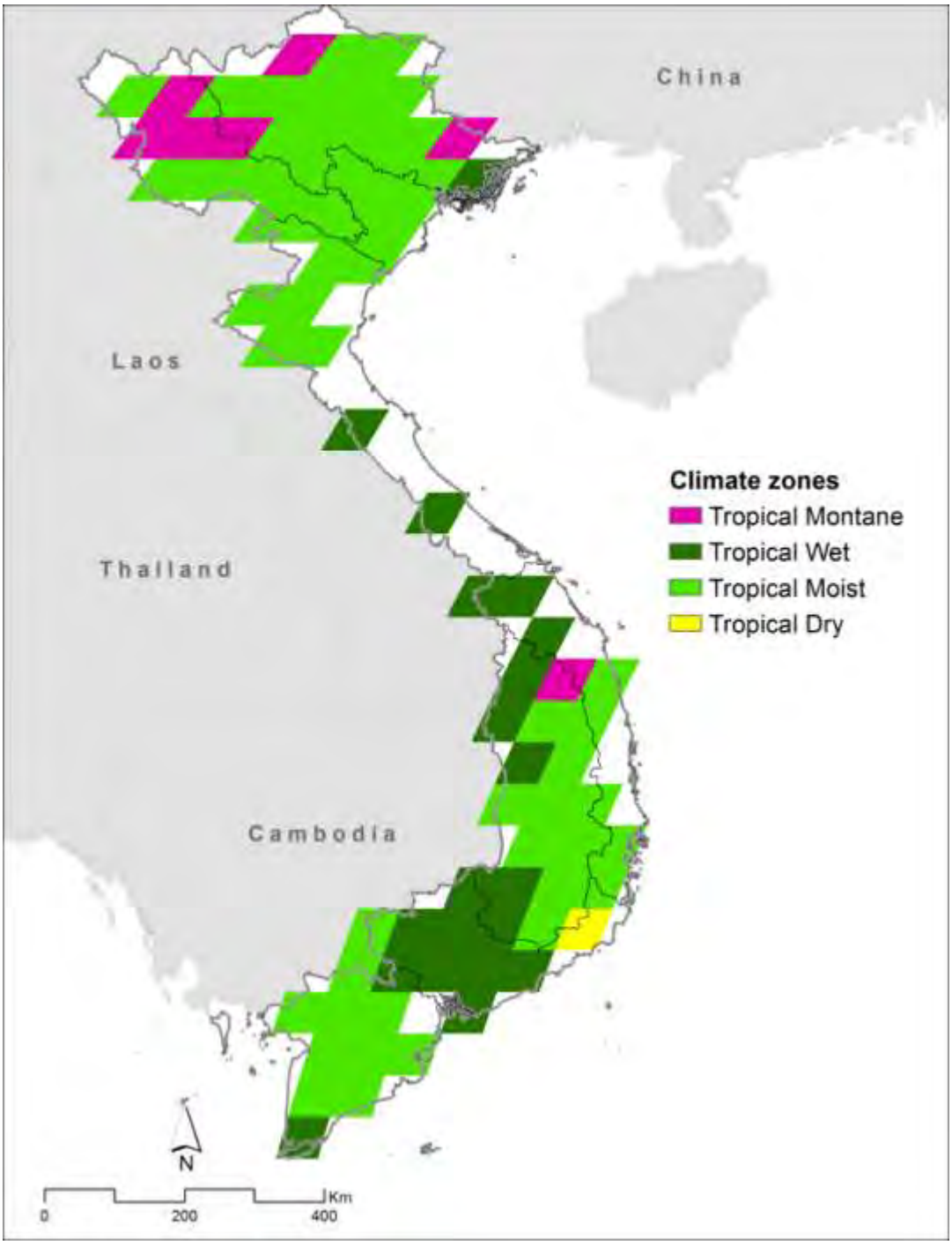


Figure V-9. Map of Climate zones across Vietnam.

8.2.5 Soil nutrient availability

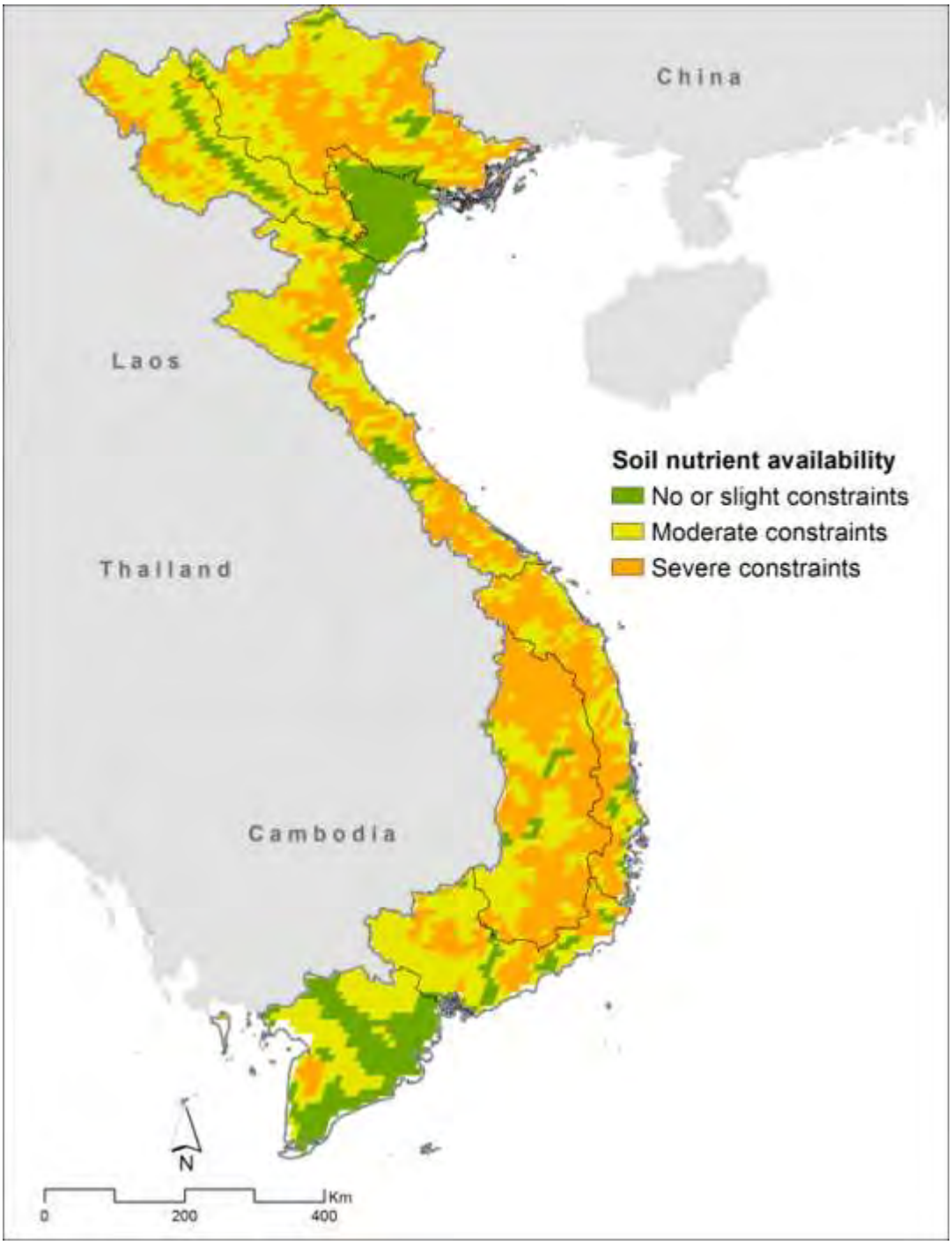


Figure V-10.Map of areas with soil nutrient availability across Vietnam.

8.2.6 Rural population growth

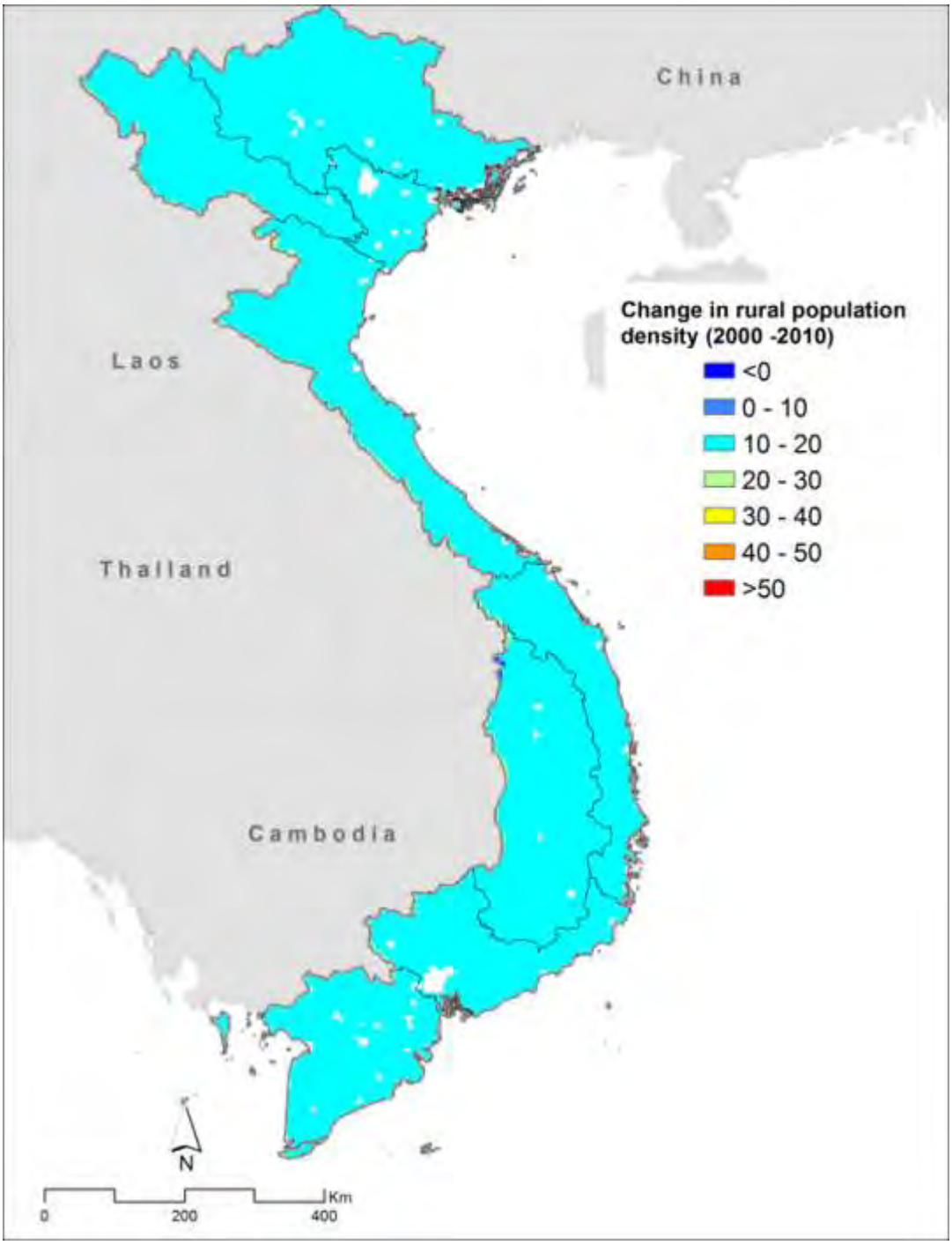


Figure V-11. Rural population growth shown as percent population density.

8.2.7 Protected areas

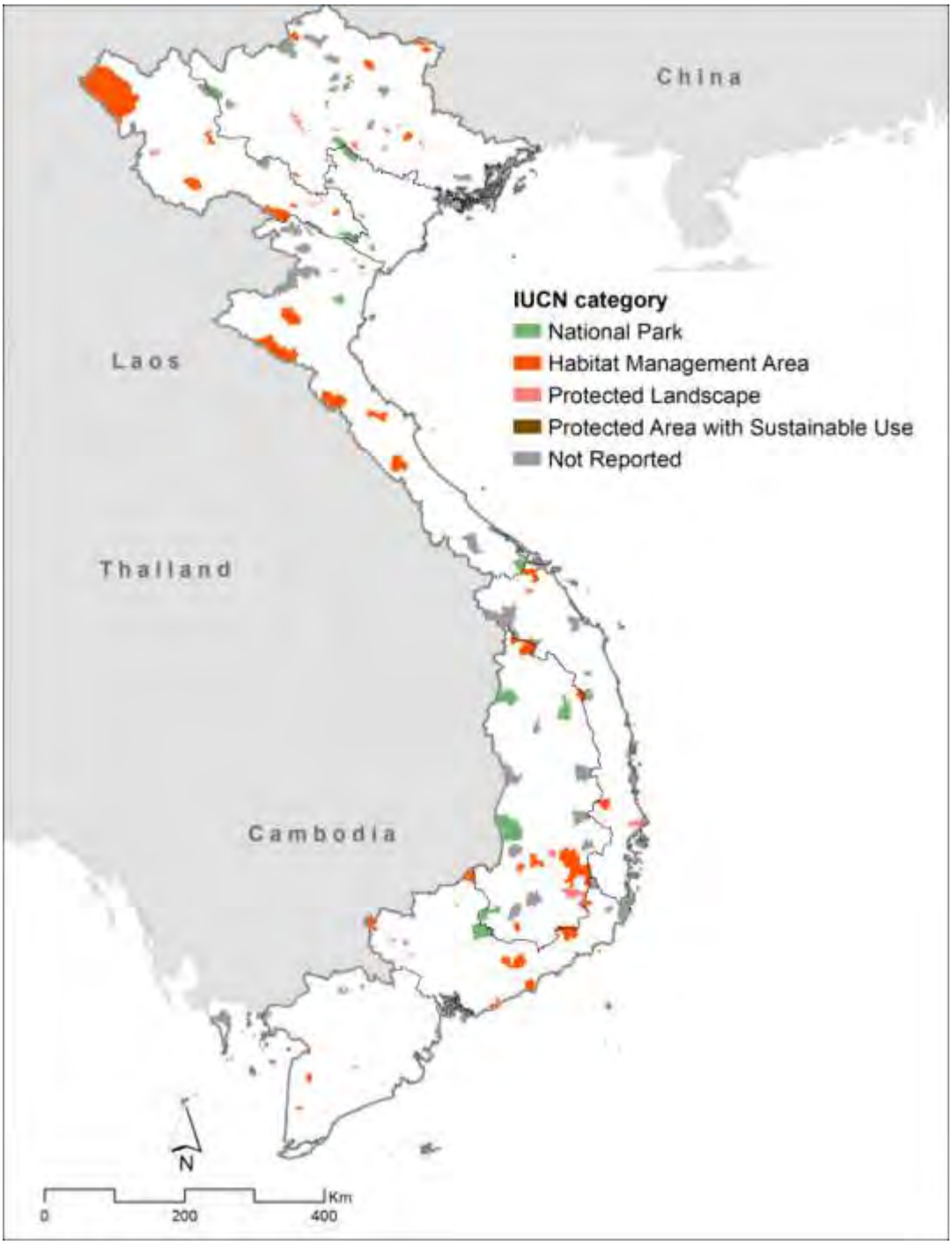


Figure V-12. Map of protected areas by IUCN category.

8.3 FOREST THREATS

This section presents spatial overlays of different factors over the 2000 map of forest cover (defined as at least 25% tree cover from MODIS VCF data) to illustrate possible threats to the forest in Vietnam in terms of potential for future deforestation. These spatial overlays present examples of how different threat for forests can be mapped with country-specific data. These examples use coarse resolution global datasets, and more detailed analysis can be done using country/province-specific data for key factors of interest.

8.3.1 Analysis #1: Forest and carbon stocks

The quantity of CO_2 emissions released into the atmosphere from the conversion of forest to other land uses depends on the amount carbon stored in the forest. Understanding where forests with high carbon stocks, and thus potential for high emissions from deforestation, are located within Vietnam could provide input to decisions regarding land use planning in the country.

Figure V-13 illustrates the distribution of carbon stocks categories across forests in Vietnam. The forest carbon stocks are grouped into five categories: LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150 -200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (>250 t C ha^{-1}).

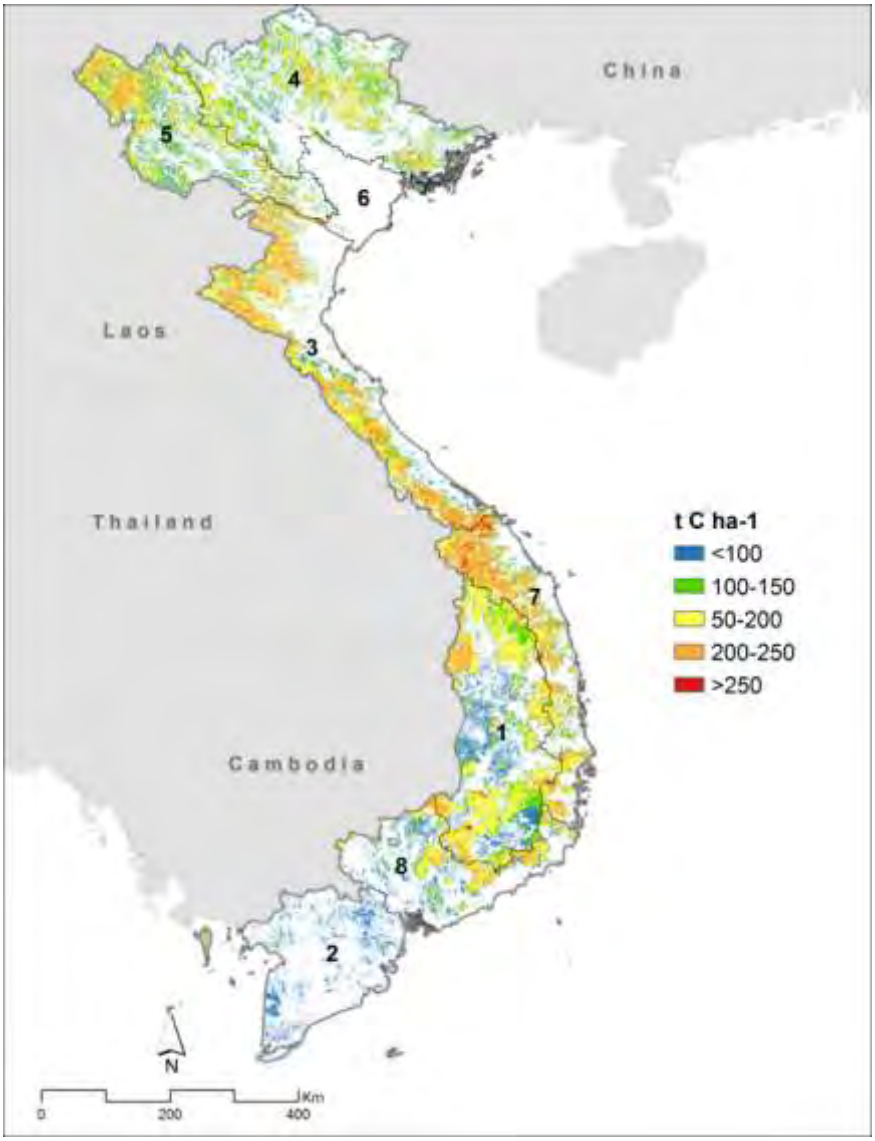


Figure V-13. Forest carbon stocks for forest cover in 2000 across Vietnam.

Table V-13 reports the percent forests per carbon stock category for provinces in Vietnam. The largest part of forests was classified in the MEDIUM HIGH carbon category (34%), followed by the LOW carbon category (25%). The least area of Vietnam"s forests was classified in VERY HIGH carbon category (1%).

Table V-6. Sub-national estimates as percent forest cover per carbon stock category. Carbon stocks categories are defined as LOW (< 100 t C ha^{-1}), MEDIUM (100-150 t C ha^{-1}), MEDIUM HIGH (150-200 t C ha^{-1}), HIGH (200-250 t C ha^{-1}) and VERY HIGH (< 250 t C ha^{-1})

Map ID	Province	Forest cover (1000 ha)	Percent forest with VERY HIGH carbon stock (%)	Percent forest with HIGH carbon stock (%)	Percent forest with MEDIUM HIGH carbon stock (%)	Percent forest with MEDIUM carbon stock (%)	Percent forest with LOW carbon stock (%)
1	Central Highlands	1,214	1	13	45	15	26
2	Mekong River Delta	2,536	24	1	2	2	95
3	North Central Coast	3,230	1	44	33	13	9
4	North East	591	0	10	33	27	29
5	North West	1,755	0	18	37	23	22
6	Red River Delta	2,409		17	17	26	40
7	South Central Coast	65	4	45	27	15	9
8	South East	2,063	0	16	31	14	39
	Vietnam	**13,862**	**1**	**23**	**34**	**17**	**25**

8.3.2 Analysis #2: Forest and agriculture suitability

Most forests are cleared for agriculture (small or large scale), and soil nutrient availability is a key factor that can be used to predict future threat to the forest. Figure V-14 illustrates the potential suitability for agriculture across forest areas in 2000 based on soil nutrient availability. Forests with slight to moderate constraints based on soil nutrient availability were considered more suitable, while forests with severe and very severe constraints were considered not suitable for agriculture. Figure V-15 illustrates the distribution of the carbon stock categories across forests with potential suitability for agriculture use in Vietnam.

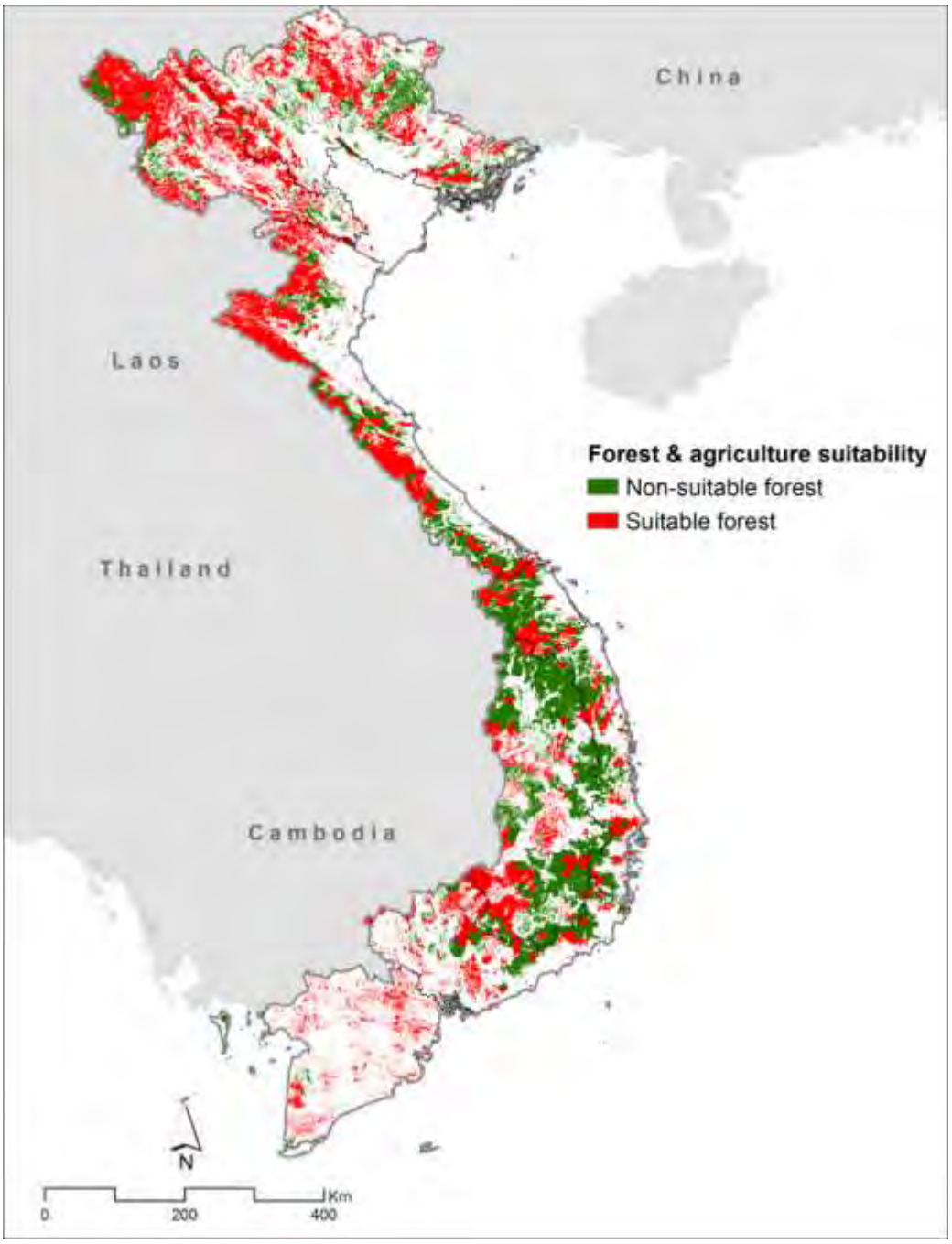


Figure V-14. Spatial overlay of forests areas in 2000 with no or slight to moderate constraints (red) and with high and very high (green) constraints on soil nutrient availability for Vietnam

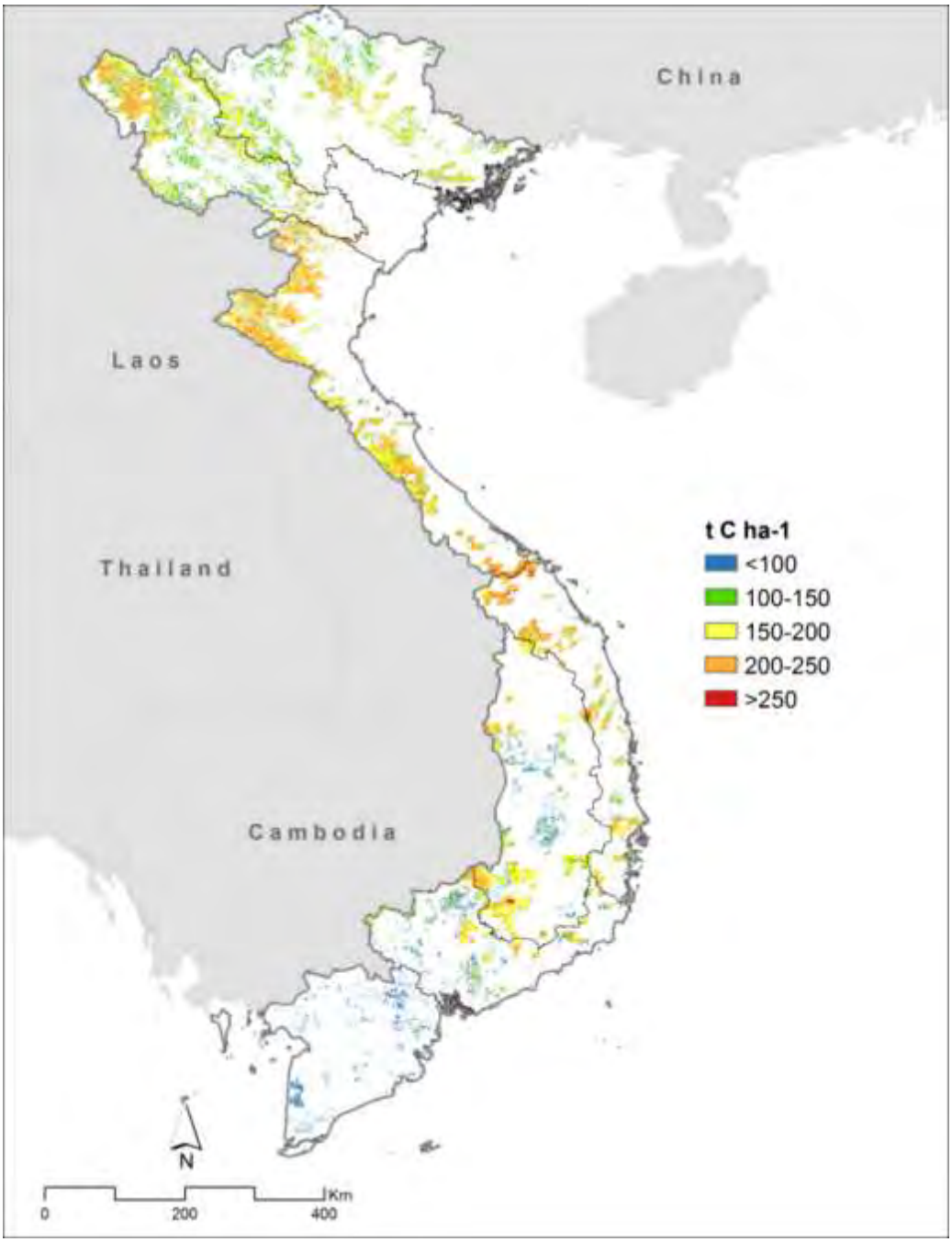


Figure V-15. Spatial overlay of forest lands suitable for agriculture and their respective forest carbon stocks

8.3.3 Analysis #3: Forest and road network

Forests close to roads are more likely to be deforested or disturbed than forests further away from roads. Using the assumption that forest areas within 5km of roads is more accessible, Figure V-16 illustrates the accessibility of forests in Vietnam. Figure V-17 illustrates the distribution of carbon stock categories across the more accessible forest, defined within the 5 km buffer zone around the roads.

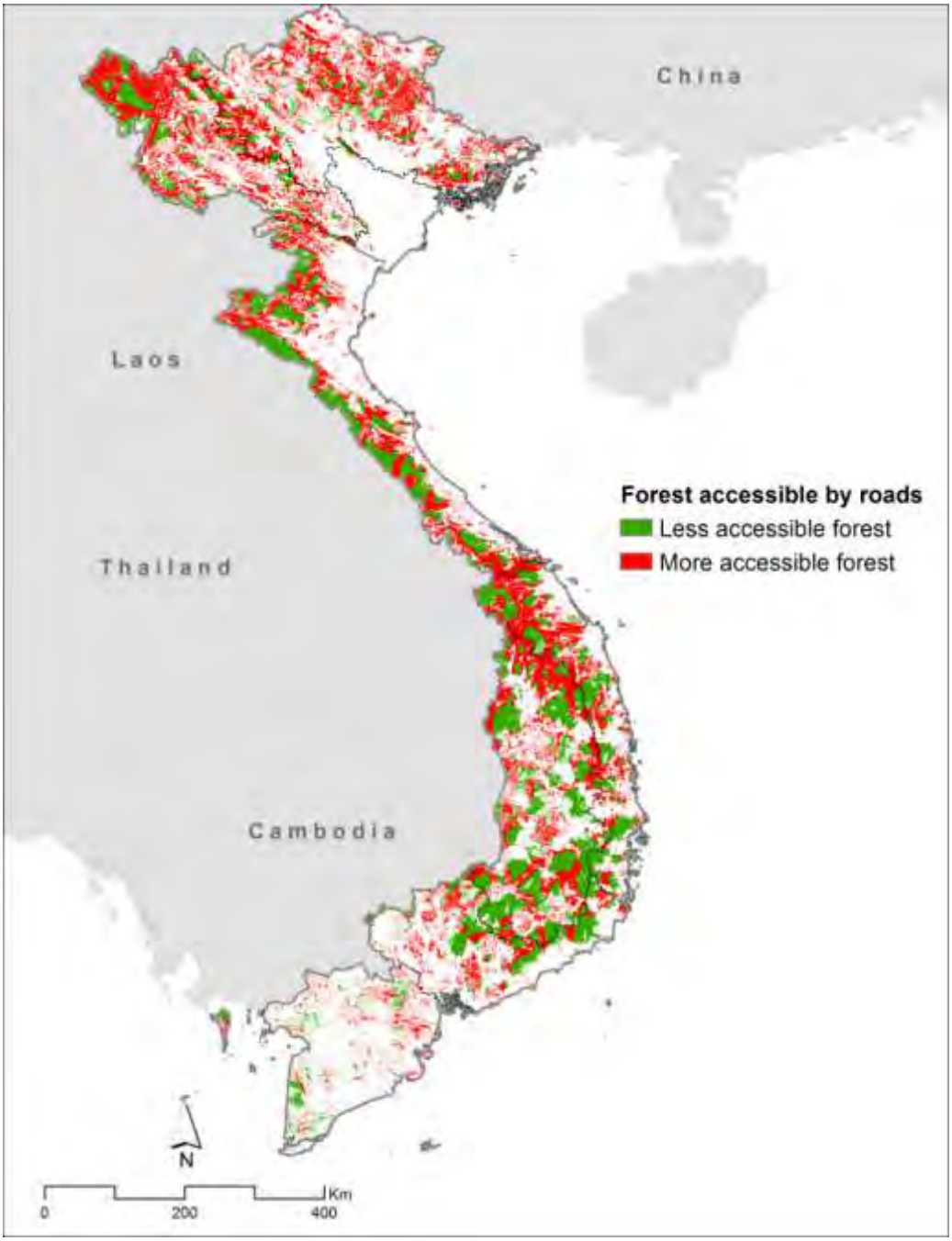


Figure V-16. Spatial overlay of forest cover in 2000 and 5 km buffer zone around road network in Vietnam. More accessible forests are defined as forests within 5 km buffer zone and less accessible forests are defined as forests outside this zone.

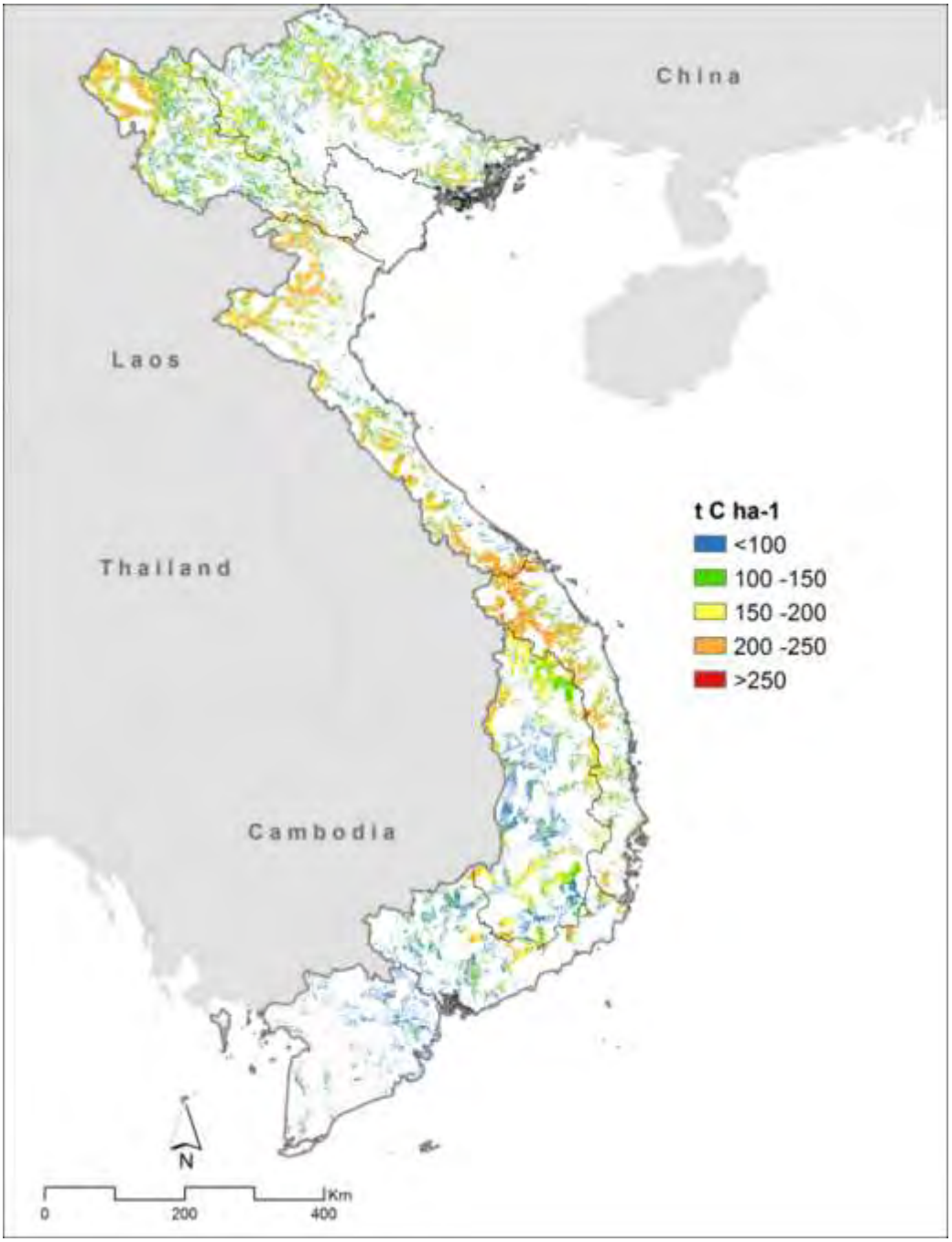


Figure 17. Spatial overlay of more accessible forest (within 5 km buffer zone around roads) and carbon stocks.

8.3.4 Analysis #4: Forest and change in population

Increases in rural population can result in increased potential threat to forests. Figure V-18 illustrates the change in population density based on the Gridded Population of the World (GPWv3) data.[9] Most of the rural areas in Vietnam had a change of population density in the 10-20% change category. If country specific data on population are available, more detailed analysis using this data could provide a clearer picture of provinces experiencing rapid change in population density that could present a threat to their forests.

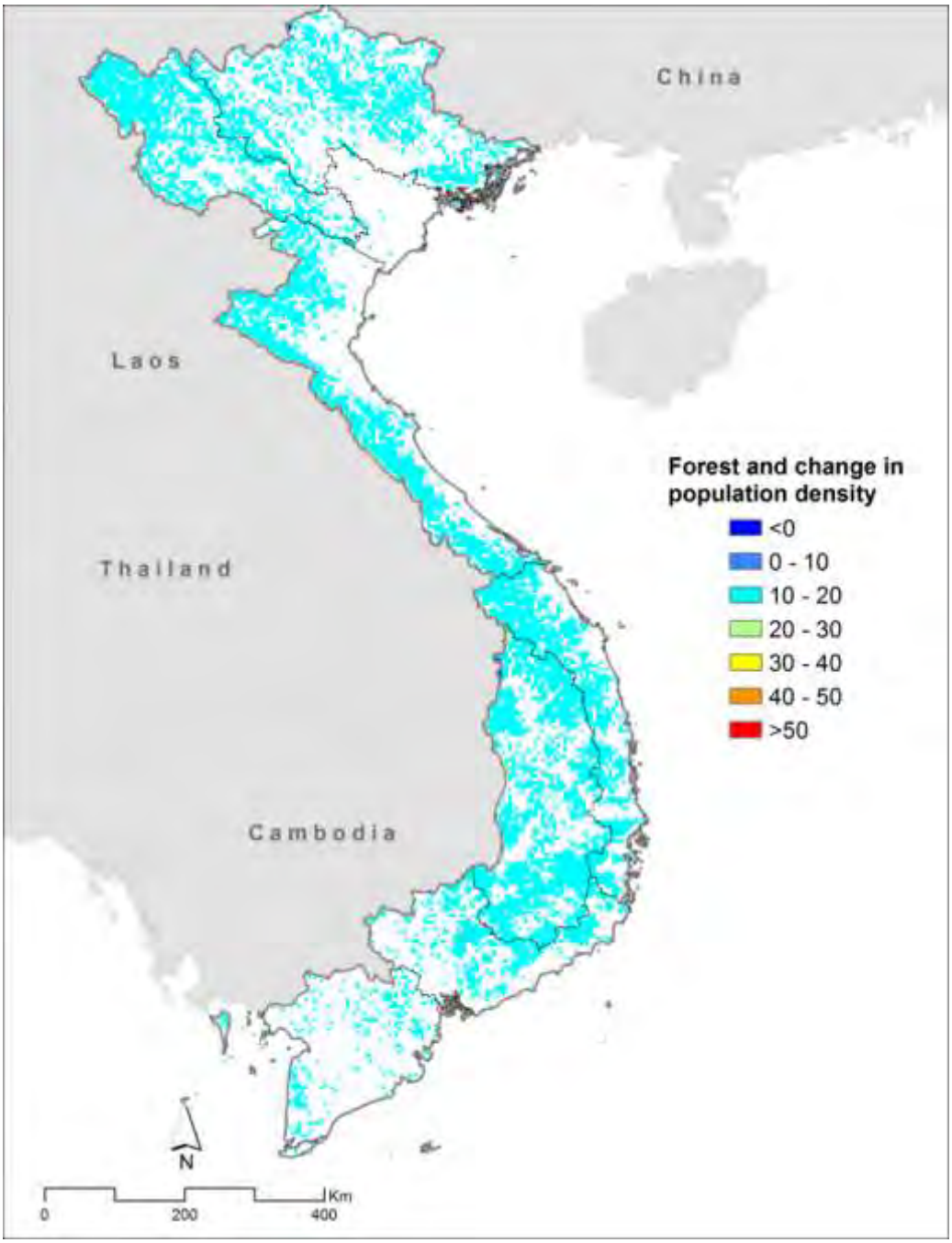


Figure V-18. Spatial overlay of forest cover and change in rural population density between 2000 and 2010

[9] Note that this does not necessarily reflect actual population growth data based on Vietnam census data.

8.3.5 Analysis #5: Forest and elevation

In most cases deforestation occurs at low elevation, where people usually live. To illustrate the potential threat to forests based on elevation, Figure V-19 shows the forest across Vietnam in three elevation categories: low (1-500m), medium (500-1,500m) and high (>1,500m). Most of the forests in Vietnam are located at low and medium elevation.

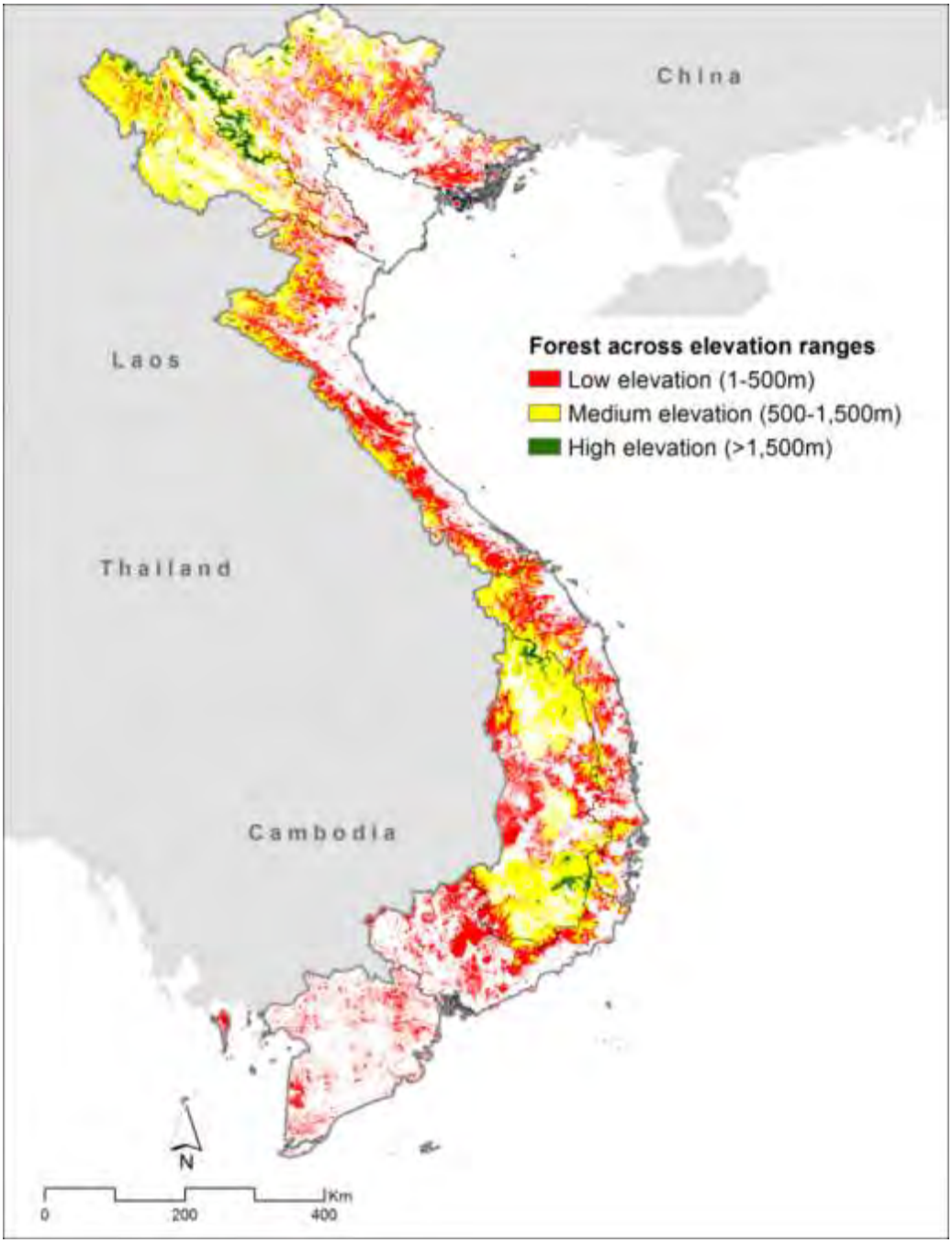


Figure V-19. Forest cover in Vietnam for 2000 by elevation classes

ANNEX A: DATA USED

This section presents an overview of the spatial datasets presented in the Atlas. **All maps and tables presented in Section 3 are based on these data sources.**

A.1 FOREST COVER

Dataset name:

Landsat-calibrated forest cover for 2000

Description:

The 2000 Landsat-calibrated[10] forest cover data were developed by the Humid Tropical Forest Monitoring Project at Geographic Information Science Center of Excellence (GIScCE), South Dakota State University[11]. The Landsat-calibrated forest cover for 2000 shows the percent of forest cover per 18.5 km by 18.5 km block and it was defined as area with tree canopy cover greater than 25% from MODIS[12] Vegetation Continuous Field (VCF) tree cover data[13,14]. The MODIS VCF 25% tree canopy data were calibrated using a relationship between the Landsat-based forests cover loss (Landsat data classified for 18.5 km sample block) and the mean VCF tree canopy density per sample block. The Landsat-calibrated forest data were used in the regional Atlas and forest cover greater than 25% derived from MODIS VCF tree cover dataset was used for the national Atlases for countries where country specific forest cover data were not available.

Source:

Percent forest cover calibrated with Landsat images at 18.5 km block can be obtained for free from the Humid Tropical Forest Monitoring Project at Geographic Information Science Center of Excellence (GIScCE), South Dakota State University web site (http://globalmonitoring.sdstate.edu/projects/gfm/humidtropics/data.html).

MODIS VCF data can be obtained for free from Global Land Cover Facility web site (http://www.glcf.umd.edu/data/vcf/)

A.2 GROSS FOREST COVER LOSS

Dataset name:

Landsat-calibrated forest cover loss for 2000-2005

Description:

This global dataset for 2000-2005 gross forest cover loss was derived from a probability–based sampling approach that combines low and high resolution satellite datasets. This dataset provides Landsat-calibrated estimated forest loss at 18.5 km resolution. MODIS-derived forest loss from VCF tree canopy cover data were sampled at 18.5 km sample blocks. For high-change sample blocks a simple linear regression model was applied to MODIS–derived forest loss data based on Landsat-derived clearing. For low-change sample blocks, a post-stratification based on VCF tree canopy cover and intact forest

[10] The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey - http://landsat.gsfc.nasa.gov/

[11] Hansen, M.C., Stehman, S.V., Potapov, P.V., Loveland, T.R., Townshend, J.R.G., DeFries, R.S., Pittman, K.W., Stolle, F., Steininger, M.K., Carroll, M., Dimiceli, C. (2008) Humid tropical forest clearing from 2000 to 2005 quantified using multi-temporal and multi-resolution remotely sensed data. PNAS, 105(27), 9439-9444.

[12] Moderate Resolution Imaging Spectroradiometer - http://modis.gsfc.nasa.gov/

[13] Hansen, M., R. DeFries, J.R. Townshend, M. Carroll, C. Dimiceli, and R. Sohlberg (2006), Vegetation Continuous Fields MOD44B, 2001 Percent Tree Cover, Collection 4, University of Maryland, College Park, Maryland, 2001.

[14] Hansen, M., R.S. DeFries, J.R.G. Townshend, M. Carroll, C. Dimiceli, and R.A. Sohlberg (2003), "Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm", Earth Interactions, Vol 7, No 10, pp 1-15.

landscape data were used to estimate the forest loss based on sample mean Landsat-derived clearing within a post-strata. The global dataset was clipped to the boundaries of the LEAF country to illustrate the forest cover loss for 2000-2005 across the region.

Source:

The forest cover loss 2000-2005 data are available for free from Geographic Information Science Center for excellence, South Dakota State University web site (http://globalmonitoring.sdstate.edu/projects/gfm/humidtropics/data.html).

A.3 BIOMASS CARBON STOCKS

Dataset name:

Benchmark map of carbon stocks across tropical countries for early 2000

Description:

The biomass carbon stock map (t C/ha in above and below ground) was developed by Saatchi et al. 2011[15] at 1 km resolution across pan-tropical countries. It used a robust approach to model above ground biomass (AGB) in live vegetation by combining data for 4,079 in situ inventory plots, samples of forest structure from light detection and ranging (Lidar) satellite images, as well as optical and microwave imagery at 1 km resolution. The below ground biomass (BGB) was estimated using Mokany et al. 2006 equation[16]. Carbon stocks were estimated as 50% of the total biomass (AGB + BGB). Spatially explicit uncertainties of the benchmark map were estimated though error propagation spatial analysis and included errors associated with prediction of spatial modeling, and estimation of AGB and BGB. The pan-tropical carbon stock data contains datasets for the mean carbon stocks as well as datasets incorporating uncertainty (high and low) values. For the purpose of this Atlas only the dataset reporting the mean carbon stock values was used to display the range of biomass carbon stocks across the LEAF region.

Source:

The benchmark map of carbon stock with associated uncertainties is freely available at S. Saatchi"s web site at the Jet Propulsion Laboratory, California Institute of Technology (http://carbon.jpl.nasa.gov/index.cfm).

A.4 CARBON EMISSIONS FROM DEFORESTATION

Dataset name:

Carbon emissions from deforestation 2000-2005

Description:

This dataset was developed by Harris et al. (in press)[17] and spatially quantifies carbon emissions from deforestation for 2000-2005 across tropical countries. The IPCC method of combining data on forest loss and forest carbon stocks was used to estimate carbon emissions from deforestation at 90% confidence interval. Carbon emissions from the soil to 30 cm depth were included with the assumption that forest was cleared for agriculture use. For the purpose of this Atlas, the tropical carbon emissions from deforestation 2000-2005 data were clipped to the boundaries of the LEAF countries to illustrate the carbon emissions from deforestation across the region.

Source:

---

[15] Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E., Salas, W., Zutta, B., 10 Buermann, W., Lewis, S., Hagen, S., Petrova, S., White, L., Silman, M., Morel, A. 2011. 11 Benchmark map of forest carbon stocks in tropical regions across three continents. Proc. 12 Nat. Acad. Sci. Early Edition, www.pnas.org/cgi/doi/10.1073/pnas.1019576108

[16] Mokany K, Raison RJ, Prokushkin AS (2006) Critical analysis of root:shoot ratios in terrestrial biomes. Glob Change Biol 12:84–96.

[17] Harris, NL, Brown S, Hagen SC, Saatchi SS, Petrova S, , Salas W, Hansen MC, Potapov, PV. and Lotsch, A. Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. Science (in press)

Carbon emissions from deforestation 2000-2005 datasets are available at Applied GeoSolution, LCC website (http://www.appliedgeosolutions.com/science-paper.html) and soon will be available on the Winrock International website (http://www.winrock.org/).

A.5 ROADS

Dataset name:

Road network

Description:

The road network dataset for the LEAF region was downloaded from GIS Data Depot"s GeoCommunity web site and it was developed by digitizing roads from topographic maps with different scales for different countries. Although the road layer contains information on three types of road ((1) duel line, (2) primary & secondary roads, and (3) tracks, trail and footpath)), most of the roads for the LEAF region were classified as primary and secondary.

Source:

The road network dataset is available at country level from GeoCommunity website (http://data.geocomm.com/).

A.6 SETTLEMENTS

Dataset name:

Settlements

Description:

The settlements were extracted from the complete file of geographic names for geopolitical areas from the National Geospatial-Intelligence Agency GEOnet Names Server (GNS). Locations of the settlements in GNS file are given with their coordinates and were converted to points with ArcGIS. The GNS file for only the LEAF counties was used in the Atlas.

Source:

Complete files of geographic names per country are available free of charge at the Geospatial-Intelligence Agency GEOnet Names Server website (http://earth-info.nga.mil/gns/html/namefiles.htm).

A.7 CLIMATE

Dataset name:

Climate zones

Description:

This dataset was developed for the LEAF region based on the IPCC 2006 Guidelines for Agriculture, Forestry and Other Land Use (AFOLU) climate zone data and expert knowledge of the climate zones in the region. The climate zone classification was based on elevation, mean annual temperature (MAT), mean annual precipitation (MAP), mean annual precipitation to potential evapotransporation ratio (MAP:PET), and frost occurrence.

Source:

The climate zone database for the LEAF region is available from Winrock International. The IPCC climate zone data were provided to Winrock International by the Institute for Environment & Sustainability, Italy (http://eusoils.jrc.ec.europa.eu/).

A.8 SOIL

Dataset name:

Soil nutrient availability

Description:

Soil nutrient availability dataset was developed by the International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization on the United Nations (FAO) as part of the GAEZ[18] and were estimated based on soil texture, soil organic carbon, soil pH and total exchangeable bases. For this Atlas, the global dataset was clipped to the boundaries of the LEAF countries to define the soil nutrient availability across the region.

Source:

Soil nutrient availability dataset can be downloaded for free at http://www.iiasa.ac.at/Research/LUC/GAEZv3.0/.

A.9 PROTECTED AREA

Two spatial datasets on protected areas were used in the Atlas. The first dataset defines the location and type of the protected areas, while the second dataset defines the areas within the protected areas with restriction for agriculture use.

Dataset 1 name:

2010 World Database on protected Areas (WDPA)

Description:

Protected areas were extracted from the 2010 World Database on Protected Areas (WDPA) annual release[19] and include all nationally designated (e.g. national parks, natural reserves) and internationally recognized protected areas (e.g. UNESCO world heritage sites, Ramsar wetlands of international importance). In addition to location of the protected areas, the spatial data contain information such as, name, designation and classification of IUCN[20] category, which classify the area based on their management. Only protected areas for the LEAF countries are presented in this Atlas.

Source:

The World Database on Protected Area dataset can be downloaded from http://www.wdpa.org/AnnualRelease.aspx and more information on the IUCN category can be found at www.iucn.org/about/work/programmes/pa/pa_products/wcpa_categories/.

Dataset 2 name:

Protected areas – restrictions for agriculture use

Description:

Protected areas-restriction for agriculture use dataset was developed by IIASA and FAO as part of the GAEZ data and subdivides the global protected areas in types which permits or do not permit agriculture use. Globally, the GAEZ protected areas layer comprises 20% of „protected areas" where agriculture is permitted and 80% „strictly protected areas" where agriculture is assumed not to be permitted. For the purpose of this Atlas, the global dataset was clipped to the boundaries of the LEAF countries to illustrate protected areas with restriction and no restriction of agriculture use across the region.

Source:

Protected areas with restrictions for agriculture use data can be downloaded for free at http://www.iiasa.ac.at/Research/LUC/GAEZv3.0/.

A.10 POPULATION

Dataset name:

Change in population density 2000-2010

[18] IIASA/FAO, 2012. Global Agro-ecological Zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

[19] WDPA, (2009). World Database of Protected Areas, Annual Release 2009, Available at: http://www.wdpa.org/AnnualRelease.aspx.

[20] International Union for Conservation of Nature

Description:

Change in population density dataset was developed for the purpose of this Atlas based on the population density for 2000 and 2010 data developed by the Gridded Population of the World (GPWv3) project at the Center for International Earth Science Information Network (CIESIN)[21]. The GPWv3 project provides a map of population density based on population data for 1990, 1995 and 2000 at 2.5 arc-minute cell resolution as well as projected population data for 2005, 2010 and 2015 calibrated to the United Nations Food and Agriculture Programme (FAO) estimates. For the purpose of the Atlas, the change in population density was estimated as difference in population between 2000 and 2010, and then expressed as a percent of population density in 2000 to show areas of decrease and increase of population density across the region.

Source:

The GPWv3 population density data can be downloaded from the CIESIN website at http://sedac.ciesin.columbia.edu/gpw/global.jsp. The 2000-2010 change in population density dataset is created by Winrock International and the dataset is provided as supplementary data to this Atlas.

A.11 NATIONAL AND SUB-NATIONAL BOUNDARY

Dataset name:

Administrative areas

Description:

Global administrative areas database is a spatial dataset of the location of the world"s administrative boundaries and includes country boundaries as well as boundaries of administrative subdivisions such as provinces, departments, counties, etc. The spatial dataset describes the location and provided information such as name, area and subdivision type. For the purpose of this Atlas, national and first level sub-division boundaries for the LEAF countries were used.

Source:

The global administrative database can be downloaded from Global Administrative Areas website (http://www.gadm.org/).

A.12 ELEVATION

Dataset name:

Global 30 arc-second elevation (GTOPO30)

Description:

GTOPO30 is a global Digital Elevation Model (DEM) developed by the U.S. Geological Survey"s Earth Resources Observation and Science (EROS) Data Center in Sioux Falls, South Dakota. GTOPO30 was derived from a variety of raster and vector sources and it is a spatial representation of Earth"s elevation in meters at 1 km resolution.

Source:

The global GTOPO30 dataset is available from USGS EROS Data Center website (http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info).

[21] http://sedac.ciesin.columbia.edu/gpw/aboutus.jsp

For questions or comments contact:

Sandra Brown Senior Scientist
Silvia Petrova GIS Specialist
Winrock International | 2121 Crystal Drive, Suite 500 | Arlington, VA 22202, USA | www.winrock.org
office 703.302.6528 | fax 703.302.6528 | e-mail sbrown@winrock.org or spetrova@winrock.org