Appendix 1. Creation of suitability maps for oil palm expansion

We created factor maps by assessing the relationship of as many available and relevant factors as possible that potentially correlate to historical oil palm expansion, and these maps were subdivided into three main categories: (1) *landscape factors* (climate, elevation, slope, soil type, land cover type); (2) *infrastructure factors* (transportation networks and human infrastructure such as rivers, roads, railways, cities, settlements, oil palm mills); and (3) *social and administrative factors* (oil palm concessions, protected areas). A larger list of potential factors was reduced to a subset of those variables which 1) demonstrated a relationship with past oil palm expansion and 2) seemed at a minimum plausible given an understanding of the economic and environmental constraints on palm production.

The relationship between each individual driver and oil palm suitability is derived empirically from the distribution of existing plantations. The method for assigning this suitability in GEOMOD is as follows. A set of driver maps in categorical data format are specified by the user as GEOMOD inputs. For variables which are naturally continuous (e.g. elevation), they must be broken into bins and converted into categorical format. GEOMOD identifies the proportion that a given category/bin is occupied by the land-cover class of interest – in this case, palm plantations. Bins with a higher proportion of observed palm are assigned a higher suitability, and are allocated change cells before cells with lower suitability. When multiple driver variables are analyzed simultaneously, GEOMOD analyzes each unique combination of bins from multiple variables as a single discrete bin. In a simple example, for a model built with two driver variables, each containing two bins, GEOMOD would analyze palm prevalence (and subsequently assign suitability), in up to four unique different driver bin combinations (Table A1 and Equation 1).

All raster datasets were resampled from 30m to 250m resolution. The 250m resolution was selected based on the smallest unit area of land present in the land cover maps. The smallest units of land were roughly 500x500m (25ha), therefore 250m was selected to ensure that the smallest land cover units would be represented after resampling.

Table 1. Example of GEOMOD process for developing a suitability score.

		Roads < 5km	Roads >5km
Observed Palm Count	Soil Clay Content > 20%	45 of 100	3 of 20
	Soil Clay Content > 20%	16 of 80	1 of 30
Suitability Score	Soil Clay Content > 20%	45	15
	Soil Clay Content > 20%	20	3.3

Equation 1.

$$R(i) = \left[\sum_{a=1}^{A} \{W_a \times P_a(i)\}\right] \div \left[\sum_{a=1}^{A} W_a\right] \quad \textbf{(1)}$$

Where:

R(i)	=	suitability value in cell(i),
a	=	a particular factor map,
A	=	the number of factor maps,
W_a	=	the weight of factor map a, and
$P_a(i)$	=	percent-developed in category a_k of factor map a, where cell(i) is a member of category a_k.

Factors used to develop suitability maps for each region are described below.

Climate, Precipitation:

Table A2. Rainfall suitability classes for growing oil palm

Growth Limitations	Mean Annual Precipitation (mm)	Percent of Study Area (below 1000m)
None	2,501 - 3,500	54.6%
Slight	1,701 - 2,500 3,501 - 4,000	36.9%
Moderate	1,451 - 1,700 4,001 - 5,000	7.1%
Severe	1,250 - 1,450 5,001 - 6,000	1.2%
Very Severe	< 1,250 > 6,000	0.02%

Average annual mean temperature and average annual precipitation were assessed for their suitability for oil palm growth based on Paramananthan 2003
(Precipitation: Table A2 and Figure A2)
(Temperature: Table A3 and Figure A3).

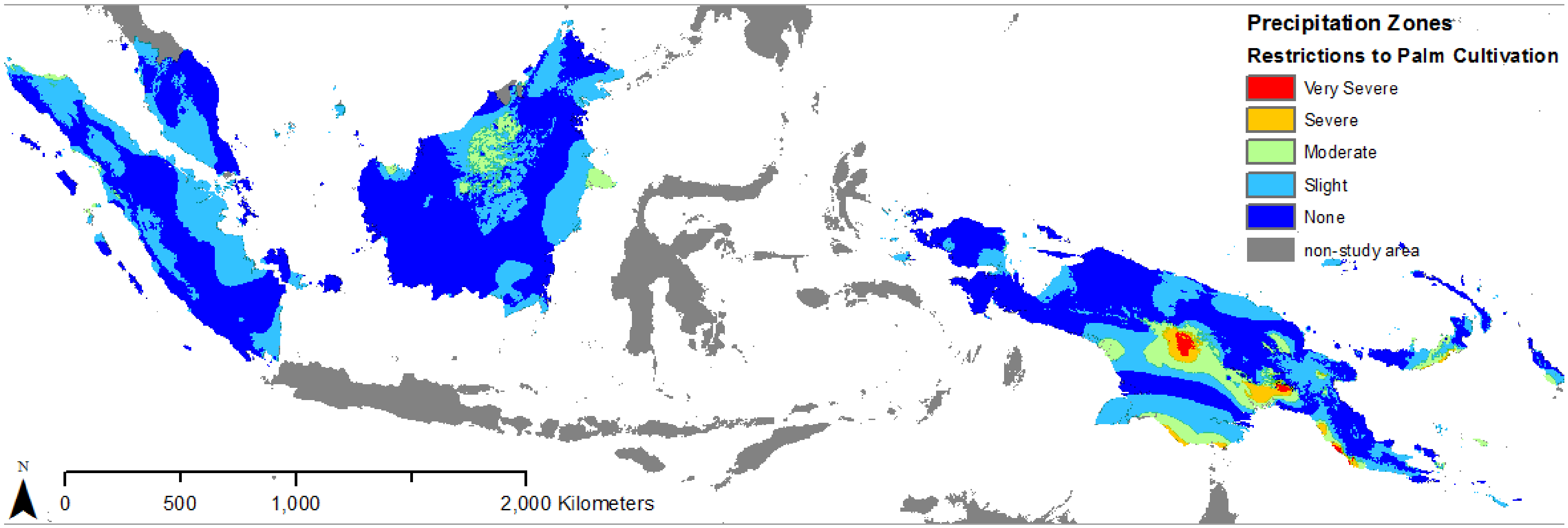

Figure A2. Precipitation zones for palm oil cultivation.

Climate, Temperature:

Table A3. Temperature suitability classes for growing oil

Growth Limitations	Mean Annual Temperature (C)	Percent of Study Area (below 1000m)
None	25 – 29	79.0%
Slight	22 – 25 29 – 32	17.4%
Moderate	20 – 22 32 – 35	3.3%
Severe	10 – 20 35 – 37	0.04%

Analysis of the study area shows that over 90% of the surface below 1000 m elevation exhibits precipitation and temperature ranges which place either no limitations, or only slight limitations, on palm cultivation. Because the study site straddles the equator, warm and moist conditions are highly consistent across regions. Therefore, it was determined that climatic variables were poor indicators to use in distinguishing between the suitability of different areas.

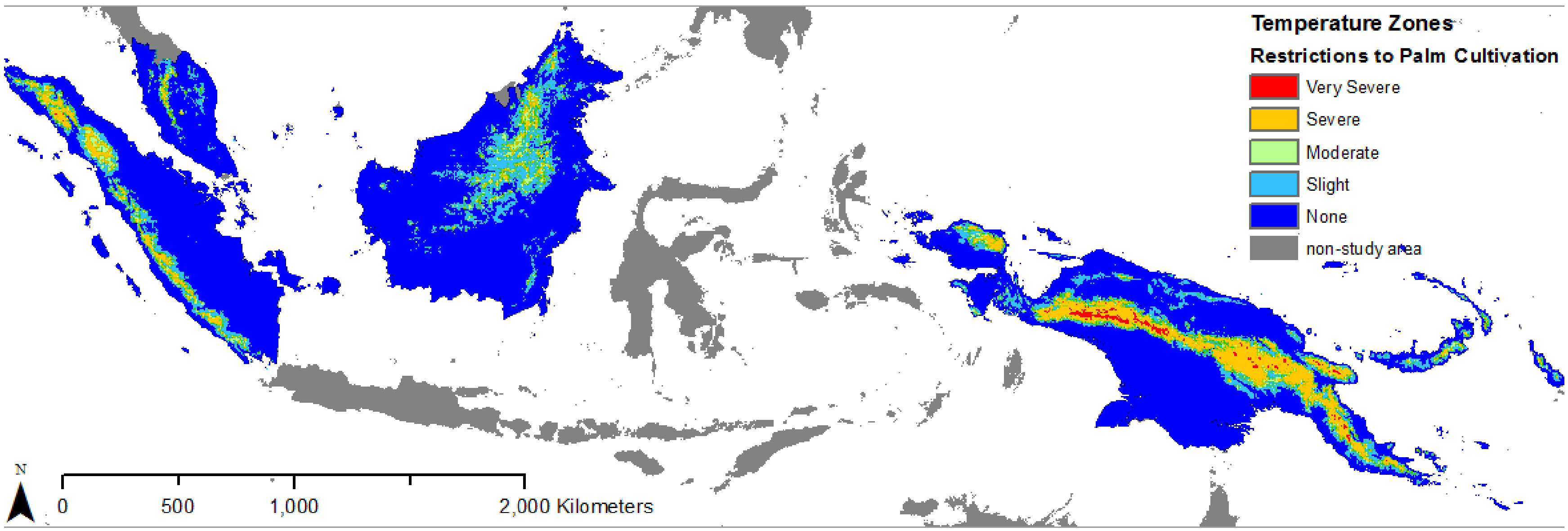

Figure A3. Temperature zones for palm oil cultivation.

Elevation:

Table A4. Elevation class suitability classes for growing oil palm.

Elevation (m asl)	Percent of Total Palm Plantations
0 – 100	**77.7%**
100 – 200	**18.1%**
200 – 300	**2.3%**
>300	**1.9%**

Existing oil palm development patterns have shown a strong affinity for low-elevation regions, with 96% of plantations in 2010 existing below 200 m. Elevation is strongly correlated with temperature and precipitation, and the climatic restrictions on cultivation increase sharply above 200-300m. Because of the demonstrated relationship between elevation and palm cultivation, and because of elevation's ability to serve as a proxy for temperature, it was included as a driver in each of the six modeled regions. Elevation was classified into bins of 100m for analysis (Table A4, Figure A4).

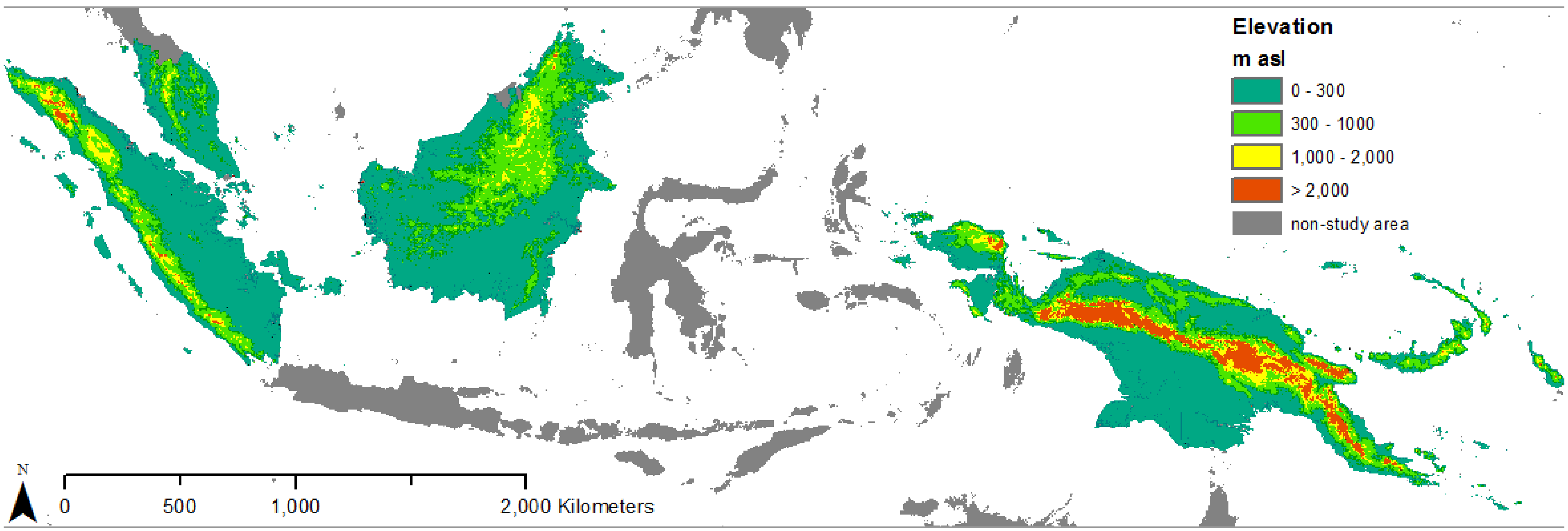

Figure A4. Elevation bins for palm oil cultivation.

Slope:

Table A5. Slope suitability classes for growing oil palm.

Slope bin (% rise)	Percent of Total Palm Plantations
0 – 3%	**65.5%**
3 – 6%	**22.5%**
6 – 9%	**5.7%**
9 – 12%	**2.4%**
>12%	**3.8%**

Although highly correlated with elevation, the inclusion of slope was found to add additional accuracy to the model. The suitability of some low-lying, yet topographically complex, areas such as western Kalimantan, were recognized as having lower suitability than elevation alone would suggest. 65.5% of plantations in 2010 were found on virtually flat (< 3% rise) areas, and 94% was on land no steeper than 9%. Slope was classified into bins of 3% rise, and was used as a driver in all modeled regions (Table A5, Figure A5).

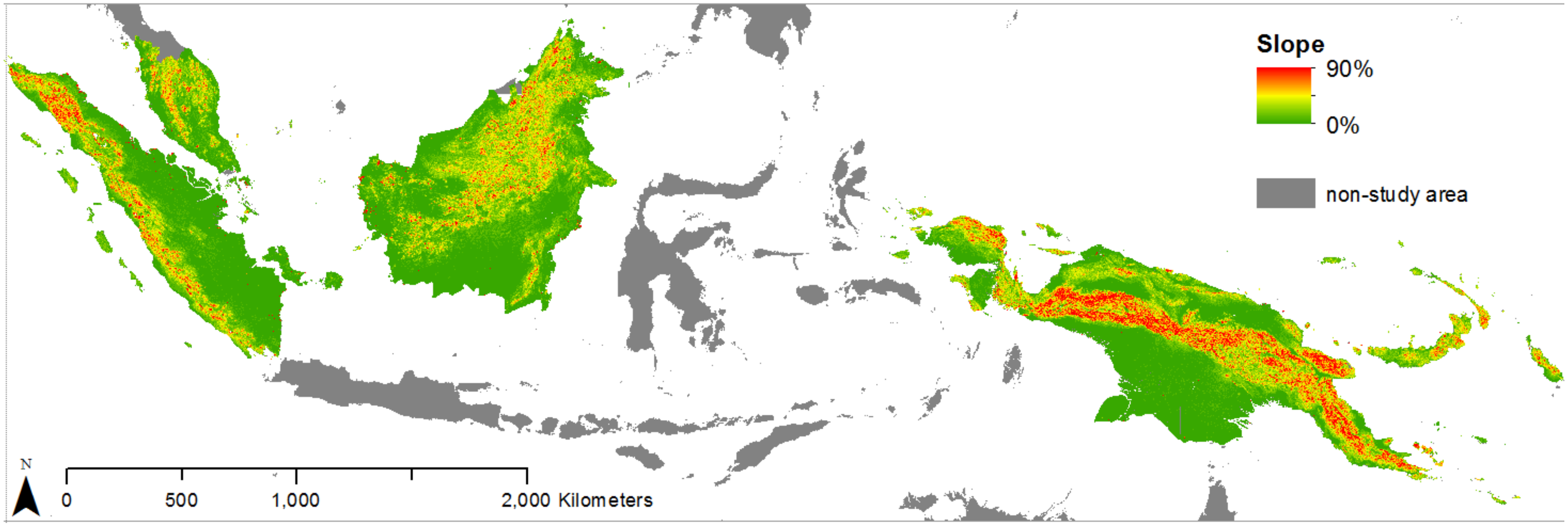

Figure A5. Slope bins for palm oil cultivation**.**

Soil:

Table A6. Soil suitability classes for growing oil palm.

Soil Class	Percent of Total Palm Plantations	Soil Class	Percent of Total Palm Plantations
Acrisols	48.9%	Plinthosols	1.0%
Histosols	14.3%	Nitisols	0.8%
Fluvisols	10.6%	Cambisols	0.7%
Gleysols	7.4%	Calcisols	0.6%
Arenosols	7.4%	Andosols	0.5%
Podzols	3.2%	Leptosols	0.2%
Ferralsols	3.1%	Luvisols	0.0%
Lixisols	1.2%	Phaeozems	0.0%

Soil type data originated from the Harmonized World Soil Database[1] and was stratified by grouping soils into major soil families. Potential development on histosols holds particular relevance for carbon emissions. Histosols are poorly drained and rich in non-decomposed organic material. In order to convert these soils to palm cultivation, the water table must be lowered, resulting in significant carbon emissions. In 2010, 14.3% of plantation were located on histosols. Acrisols, the most common type found within existing plantations, are clay-rich soils associated with tropical forests. Soil class was used as a driver of palm conversion in all six study regions (Table A6, Figure A6).

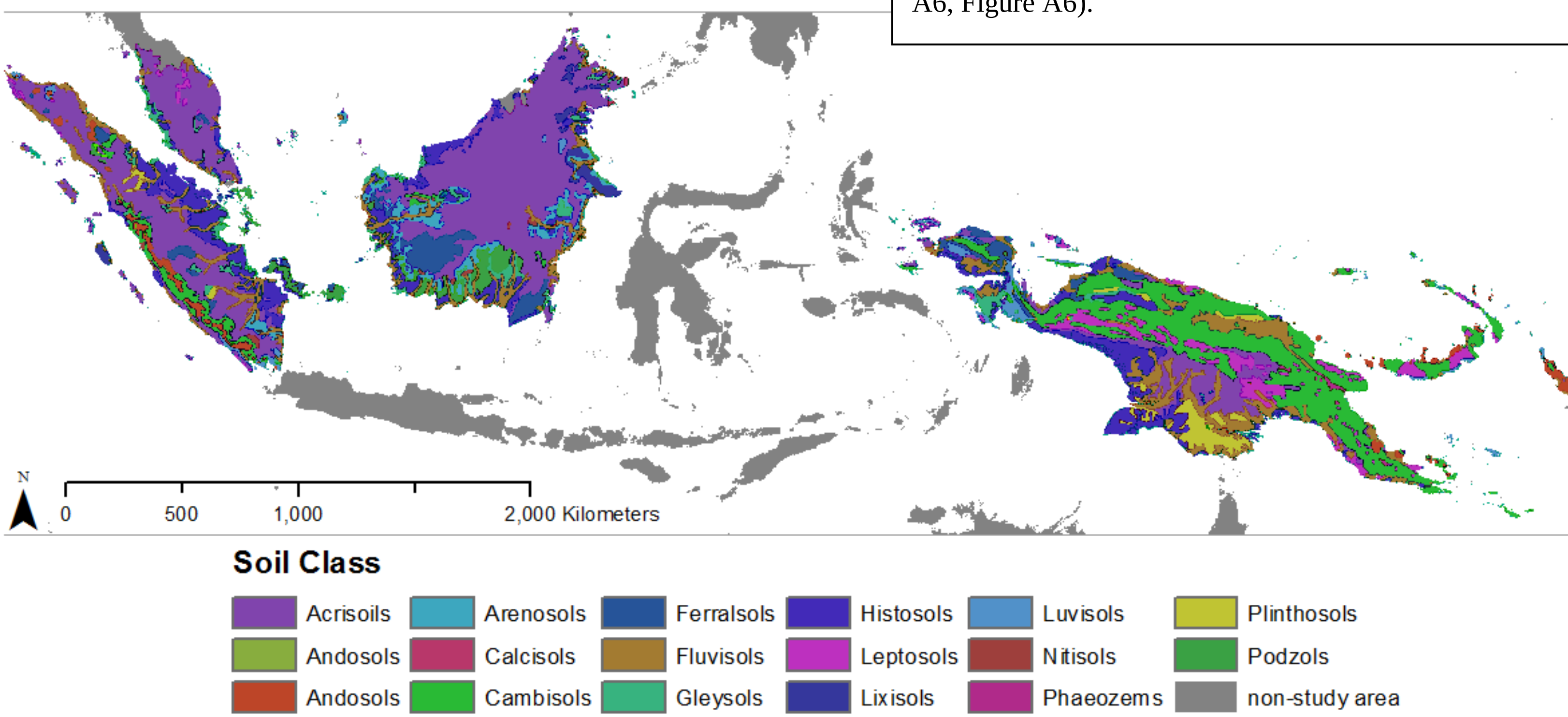

Figure A6. Soil class bins for palm oil cultivation.

Land cover:

Land cover data originated from maps developed by Gunarso et al. (2012). The original land cover categories were reclassified into 8 main land cover categories before being incorporated into the model (Figure A7).

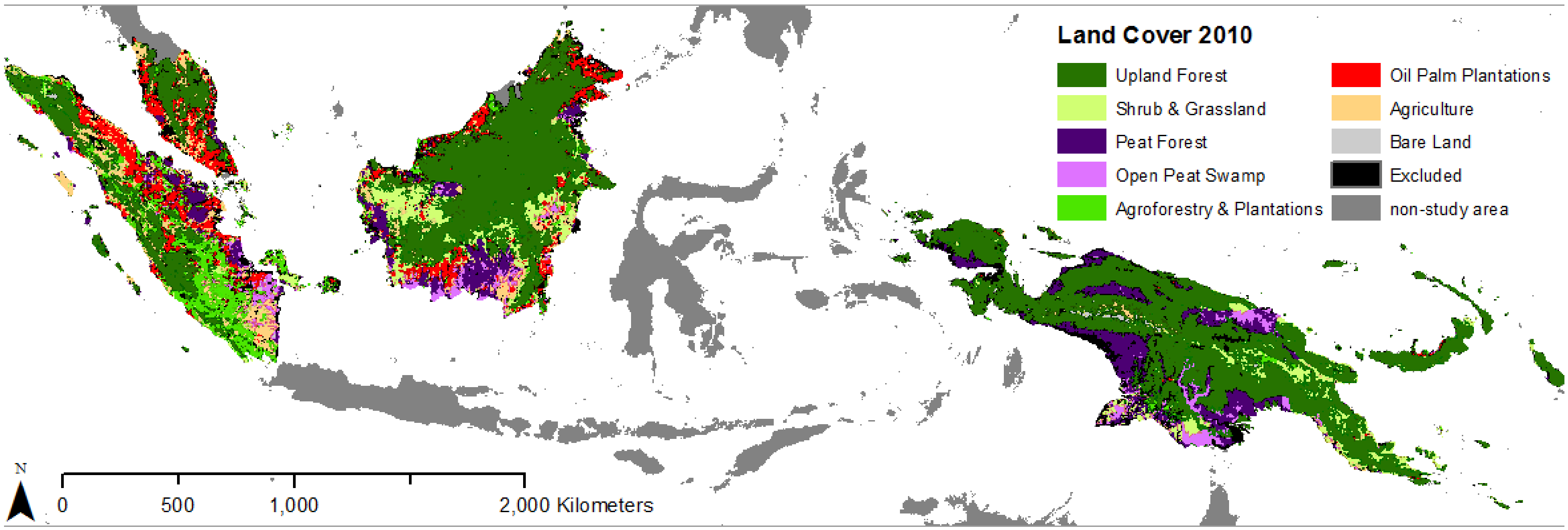

Figure A7. Land cover types used in the modelling analysis.

Transportation networks and human infrastructure

Roads:

The proximity of transportation networks was found to be an important driver of past oil palm expansion. More than 80% of existing plantations are found within 5km from a road. Suitability decreases at each 1km increment. Bins of 1km were used for the Distance to Roads driver, and the driver was included in the model of each study region (Table A7).

Table A7. Distance to roads suitability for growing oil palm.

Distance to Roads Bins (km)	Percent of Total Palm Plantations	Distance to Roads Bins (km)	Percent of Total Palm Plantations
0 – 1	40.1%	6 – 7	2.8%
1 – 2	17.5%	7 – 8	2.1%
2 – 3	11.0%	8 – 9	1.6%
3 – 4	7.7%	9 – 10	1.3%
4 – 5	5.3%	>10	6.9%
5 – 6	3.7%		

Cities & settlements:

Across the entire study, proximity to settlements does not demonstrate a strong relationship with palm prevalence. Outside of the island of Papua New Guinea, settlements are sufficiently widespread that they are a poor indicator of the economic remoteness of an area. However, in Papua New Guinea in particular, exclusion of Distance to Settlements as a criterion resulted in an implausible highly-dispersed palm development pattern. Therefore, exclusively in modeling Papua New Guinea, proximity to urban development at 10km bins was used as a driver.

Oil palm mills:

Oil palm fruit must be processed within 24 hours of harvesting in order to prevent spoilage. Therefore, proximity to the nearest oil palm mill is an important factor in deciding on a site for conversion. In 2010 in Sumatra and Kalimantan, 79.1% of plantations were located within 25km of the nearest palm mill. Information on palm mill locations was available only for Sumatra and Kalimantan, and was thus included as a model driver only in those two regions. Distance to palm mills was classified into 5km bins (Table A8).

Social and administrative factors

Beyond the exclusion of protected areas, the only administrative boundaries used were oil palm concessions (Figure A8).
Oil Palm concessions are available only for Kalimantan, Sumatra, Papua and Sarawak. Analysis of the land cover maps and concession showed oil palm was highly correlated with oil palm concessions, with 31% to 65% of oil palm occurring inside concession boundaries (Table A9).

Table A8. Distance to oil palm mills as suitability for growing oil palm.

Distance to Palm Mills Bins (km)	Percent of Total Palm Plantations	Distance to Palm Mills Bins (km)	Percent of Total Palm Plantations
0 – 5	18.8%	30 – 35	2.7%
5 – 10	25.7%	35 – 40	2.2%
10 – 15	18.2%	40 – 45	1.5%
15 – 20	10.5%	45 – 50	1.8%
20 – 25	5.9%	>50	8.1%
25 – 30	4.4%		

Table A9. Percent of oil palm plantations occurring in concessions

Percent of palm plantations occurring within concession boundaries	
Kalimantan	65%
Sumatra	31%
Sarawak	48%
Papua	48%
Average, all regions	50%

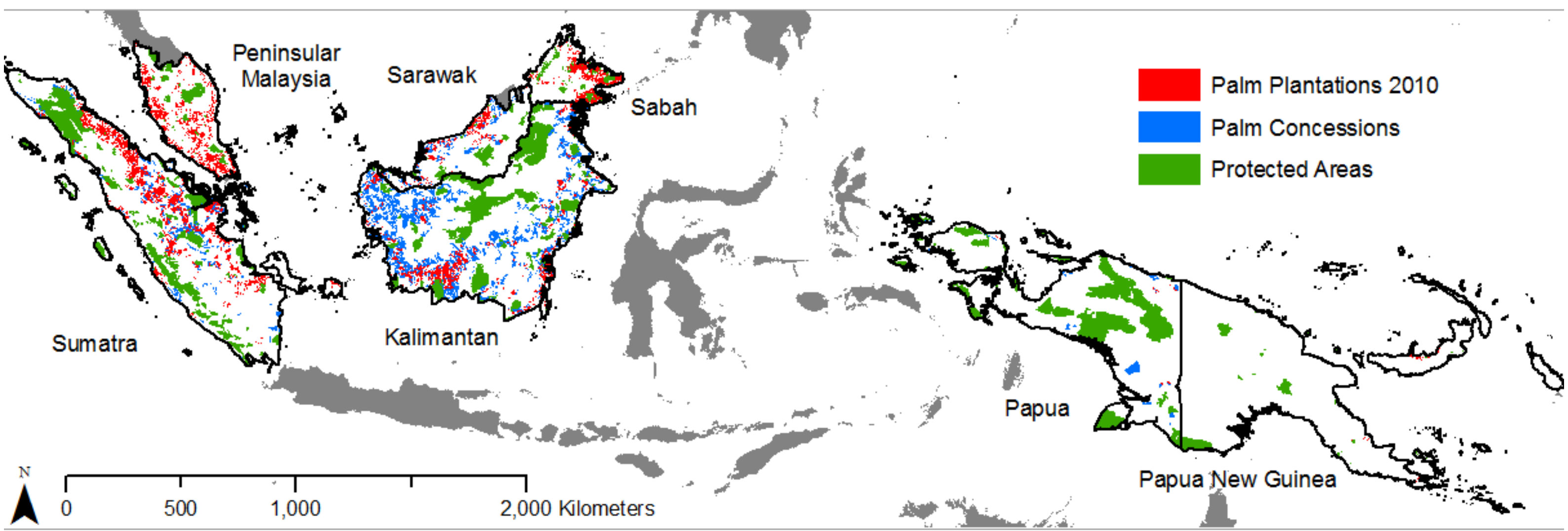

Figure A8. Oil Palm plantations, concessions and national protected areas.