Oil Palm Expansion in Indonesia

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LCLUC
Land-Cover / Land-Use Change Program

Background

- Palm oil is the most widely consumed edible oil in the world
  - The global palm oil market is expected to expand in the near future
- Indonesia is the largest supplier of palm oil
- Oil Palm is the dominant estate crop type in Indonesia, estate crop expansion plays a significant role in deforestation
- Oil palm plantation significantly reduces the carbon storage and forest biodiversity
  - Emission from forestry and land-use change are the main sources of GHG emissions of Indonesia
  - Biodiversity in Indonesia is under severe threat

Objectives

- Identify the spatial and temporal patterns of the oil palm expansion into primary (/natural) forest, at both the subnational level and grid-cell/pixel level, in Indonesia
- Improve the global agro-ecological zones model GAEZ v4 to produce potential yield maps of palm oil and other major agricultural crops for Indonesia, and estimate the annual potential economic benefit of palm oil production and alternative cropping at the grid-cell level
- Establish an econometric model to identify major driving factors and quantify the responsiveness of oil palm expansion to the major driving factors, including export quantities and prices of oil palm products over the period of 1990-2015
- Hypotheses tests and projections of future expansions

Method

- Land use and land cover changes
  - Reclassified the 23-class land use and land cover data from MoFor into 11 classes.
  - Quantified the land use and land cover conversions in three time periods
    - 1990-2000, 2000-2011, 2011-2015
- Econometric model
  - $d_{it} = exp\big(\beta_0 + \beta_1 EC_{it} + \beta_2 O_i + \beta_3 P_{it} + \beta_4 X_i' + \beta_5 S_{it} + \beta_6 S_{it}^2 + \beta_9 C_{it}' + \beta_{10} Po_{it} + \beta_{11} E_t + \varepsilon_{it}\big)$
  - Quasi maximum likelihood estimator
- Spatial panel model
  - Random effect
  - Lag, Error & Durbin

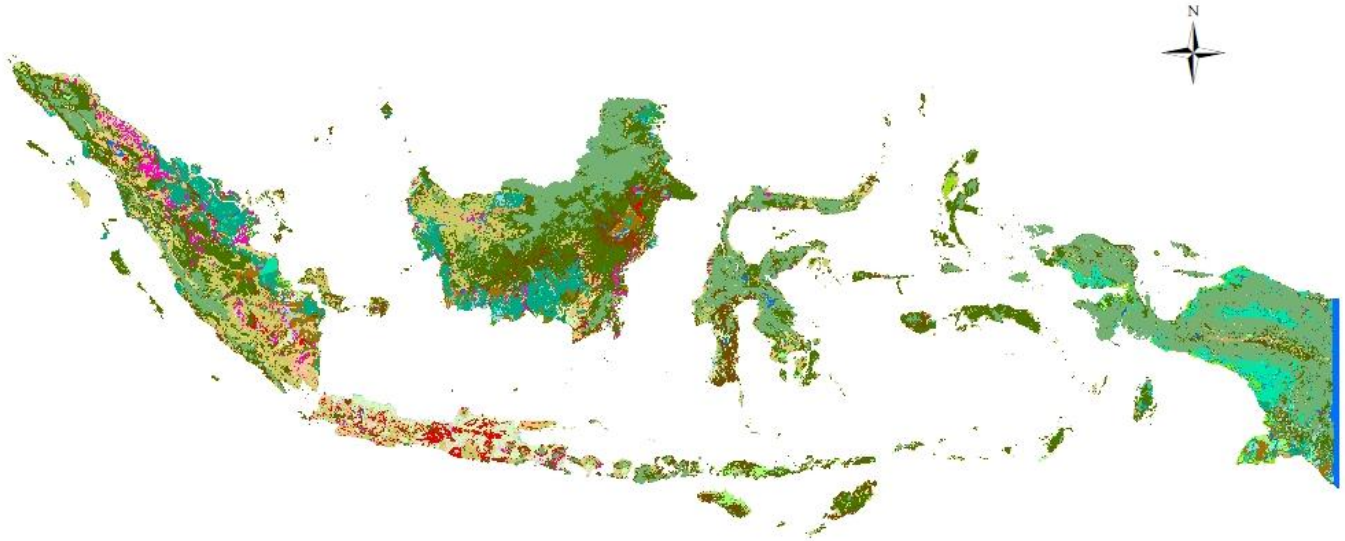
Note on the econometric model

- d_{it} is the percentage of estate crop (oil palm, in next step) area expansion into each main source type in the total area of the jurisdiction (ADM-2) *i* in year *t*.
- EC_{it} is the "long-term" potential benefit per km^2 from oil palm plantation at jurisdiction *i* in year *t*.
- O_i is the percentage of estate crop plantation in the total area of the ADM-2 jurisdiction *i* in year 1990.
- P_{it} is the percentage of the protected area in the total area of the ADM-2 jurisdiction *i* in year *t*.
- X_i is a matrix of physical factors such as slope, elevation, and AWC, and geographic factors such as density of palm oil mills and access time to large cities. These factors are largely time-invariant and play significant role in determining the conversion and transportation cost of estate crop plantation.
- S_{it} is the land cover ratio of each source land use and land cover type (forest, shrub, and dry agriculture) to the total area of the ADM-2 jurisdiction *i* in year *t*. The quadratic structure on S_{it} captures the non-linear trajectory of estate crop expansion.
- C_{it} is a matrix of climate factors such as annual precipitation, average annual temperature, and shortwave radiation at jurisdiction *i* in year *t*.
- Po_{it} is the population density of the ADM-2 jurisdiction *i* in year *t*.
- E_t is the export value/Quantity of oil palm products of Indonesia in year t.
- β_0 captures the unobserved constant determinants of estate crop expansion into each land use and land cover type.

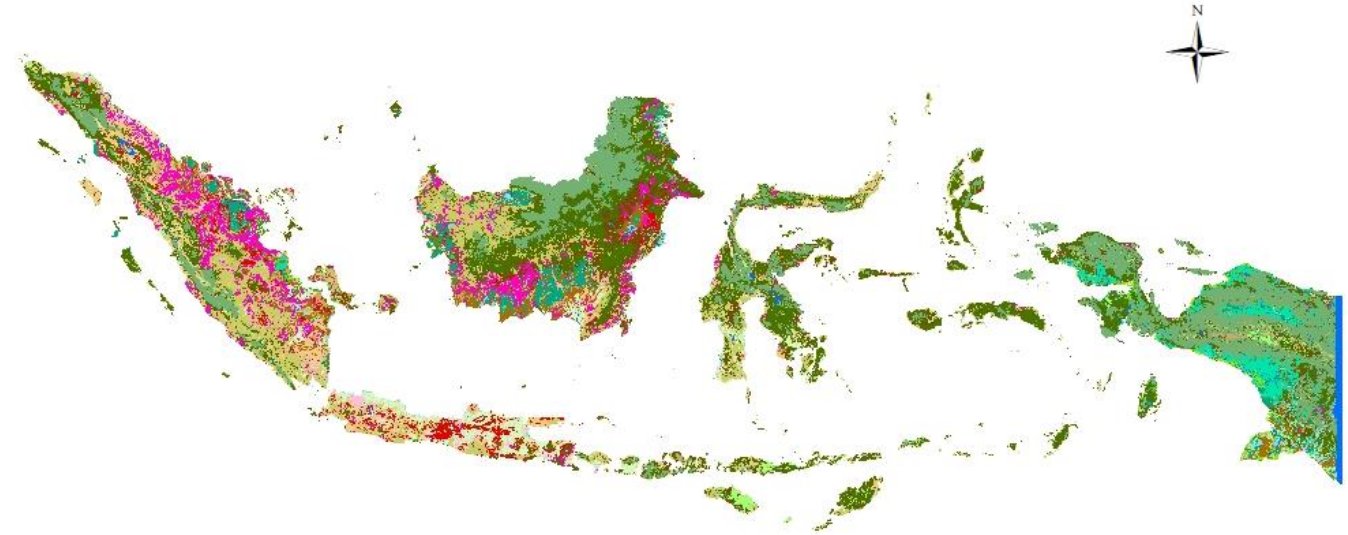
Variable Group	Variable	Unit	Data Source	Resolution
Dependent Variable	Estate crop expansion into forest in each jurisdiction	Hectare per square kilometer	Land use and land cover map (MoFor of Indonesia, 2018)	30m * 30m
	Estate crop expansion into shrub in each jurisdiction			
	Estate crop expansion into dry agriculture in each jurisdiction			
Explanatory Variables	Potential yield/revenue of oil palm plantation and dry agriculture	Ton/km^2 or USD (2000)	Potential Yield (IIASA, 2018)	10km * 10km
			Producer Prices (FAO, 2018)	
	Existing Plantation in 1990	%	Land use and land cover map (MoFor of Indonesia, 2018)	30m * 30m
	Palm oil mill density	per (100km)^2	Universal Mill List (UML) (WRI, 2018)	Point data
	Access time	minute	Travel time to major cities: A global map of Accessibility (Nelson, A., 2008)	1km * 1km
	Precipitation (Rainfall)	kg/m^{2}s	WFDEI (IIASA, 2016)	50km * 50km
	Temperature	K		50km * 50km
	Radiation (shortwave)	W/m2		50km * 50km
	Water holding capacity (WHC)	mm/m	Harmonized world soil database (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009)	1km * 1km
	Elevation	m	Shuttle Radar Topography Mission (NASA 2009)	90m * 90m
	Slope	degree		90m * 90m
	Natural forest ratio	1 unit	Land use and land cover map (MoFor of Indonesia, 2018)	30m * 30m
	Population density	person per km^2	Gridded Population of the World (GPW) (CIESIN, 2018)	1km * 1km 5km * 5km
	Protected area	%	IUCN category I-VI (WDPA, 2014)	Polygon data
	Export Value	billion USD (2000)	Export value (FAO, 2019)	

Results

Land Cover 1990



Land Cover 2015

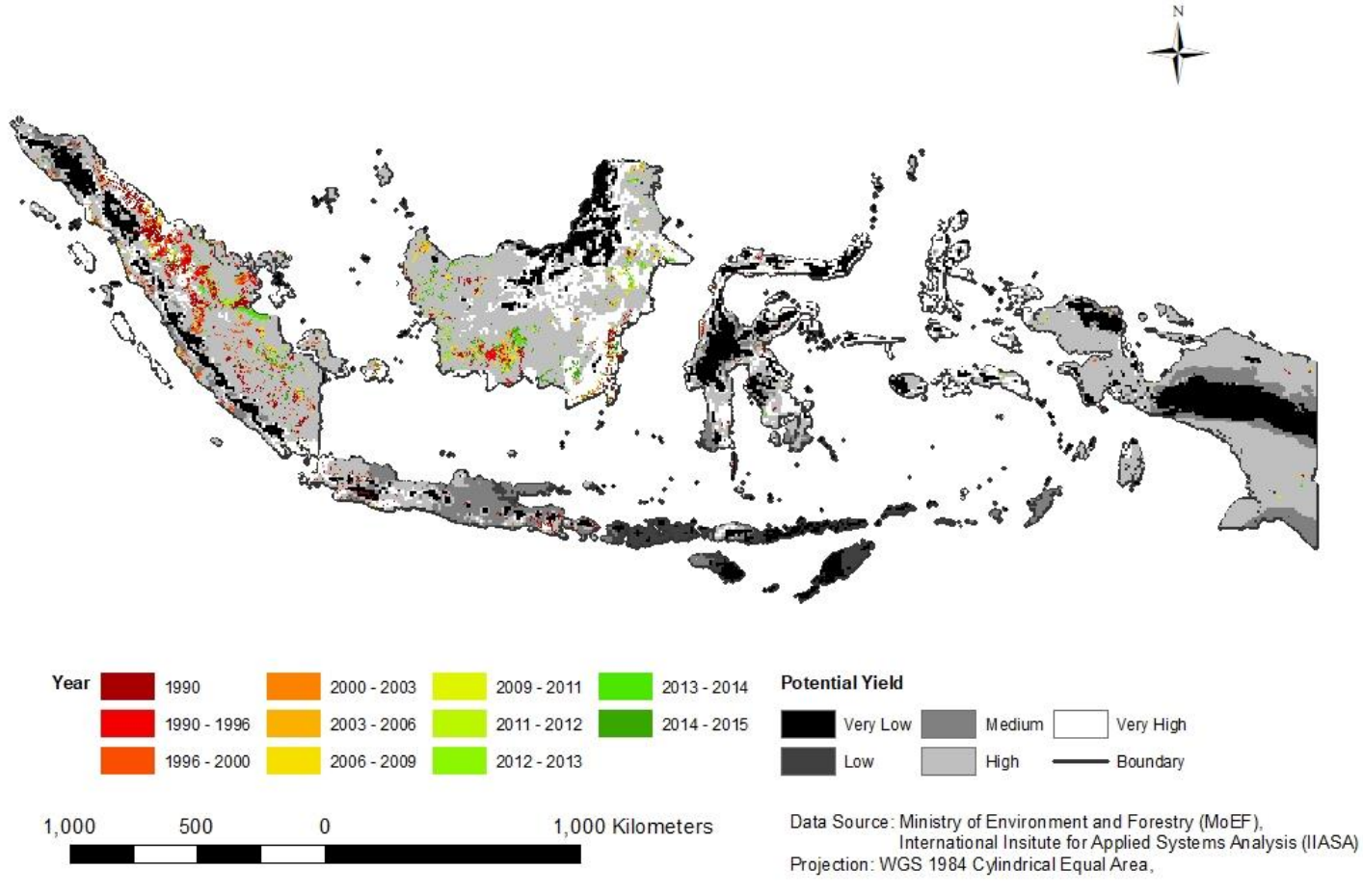


- Primary Dryland Forest
- Secondary Dryland Forest
- Primary Mangrove Forest
- Secondary Mangrove Forest
- Secondary Swamp Forest
- Secondary Swamp Forest
- Planatation Forest
- Dry Shurb
- Wet Shurb
- Pure Dry Agriculture
- Mixed Dry Agriculture
- Paddy Field
- Aquaculture
- Estate Crop
- Settlement Areas
- Port and Harbor
- Transmigration Areas
- Bare Ground
- Mining Areas
- Savanna and Grasses
- Open Water
- Open Swamp
- No Data

1,000 500 0 1,000 Kilometers

Data Source: Ministry of Environment and Forestry (MoEF)
Projection: WGS 1984 Cylindrical Equal Area

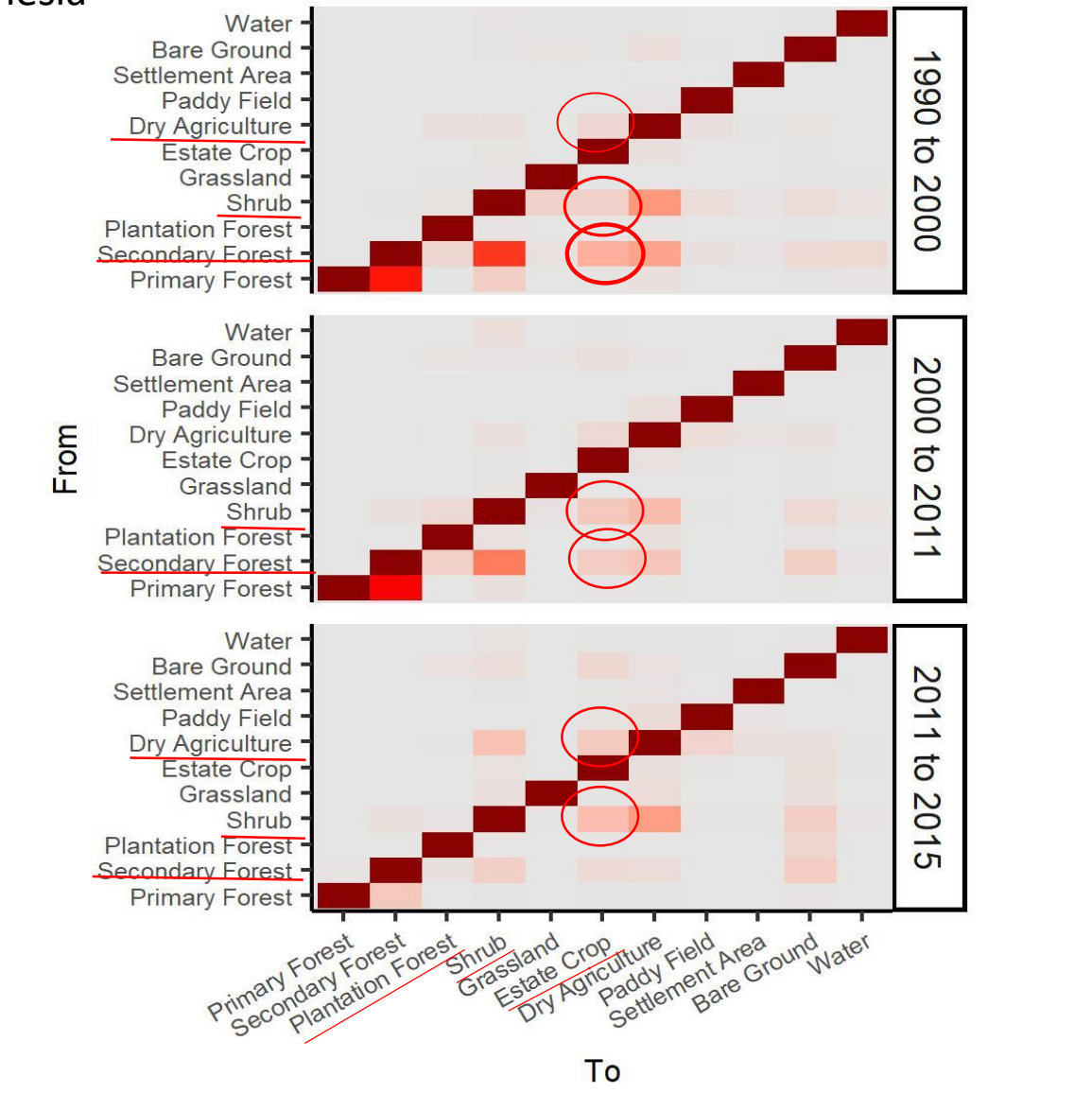
Estate Crop Expansion

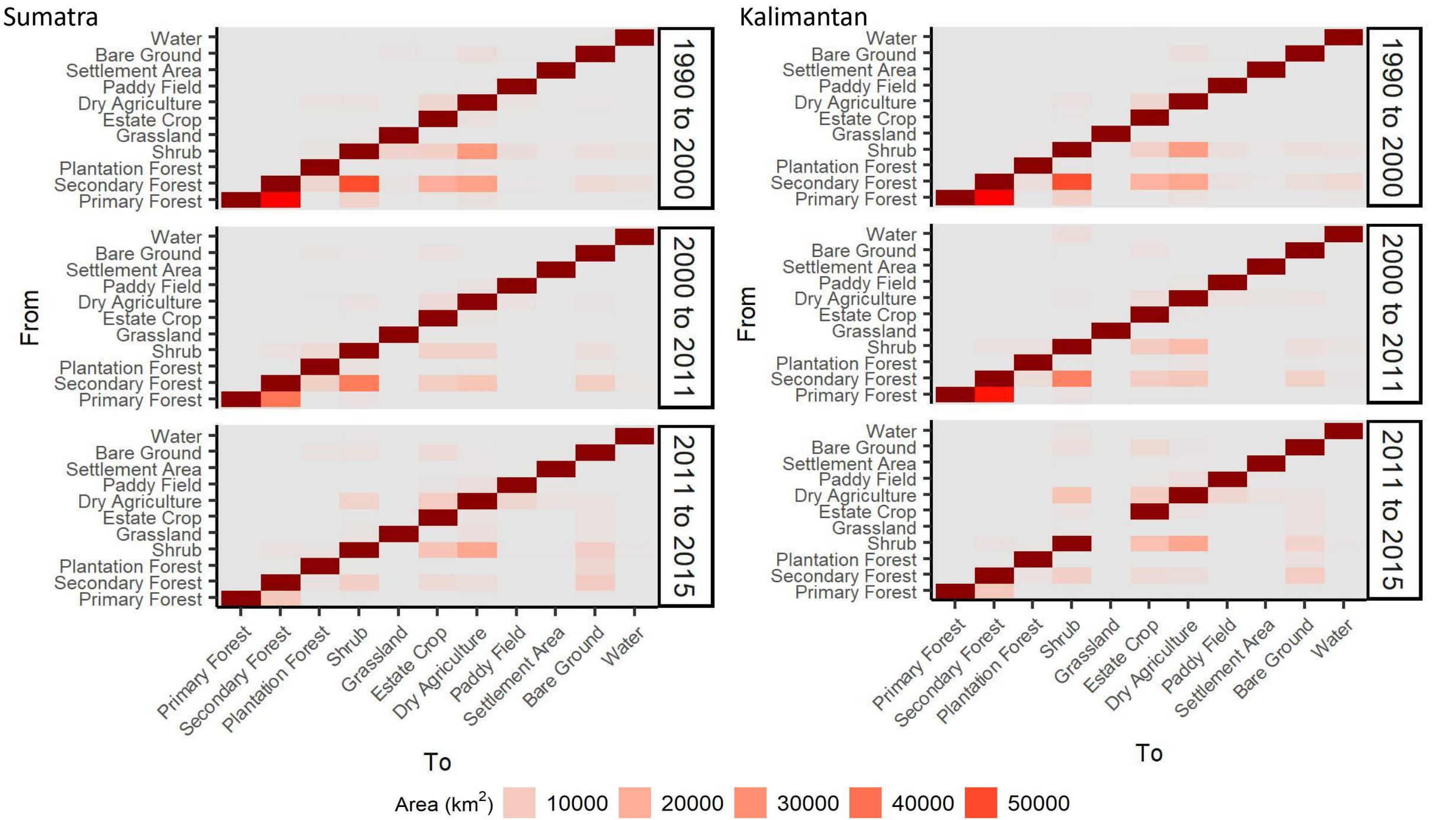


- In Indonesia, estate crop area increased from less than 45,000 km^2 to more than 120,000 km^2, with an annual average speed of 5.08% during 1990 – 2000, 3.17% during 2000 – 2011, and 5.13% in 2011 – 2015.
- More than 97% of estate crop expansion in this period occurred in Sumatra and Kalimantan. As time goes by, more expansion occurred at Kalimantan.

Note: Potential Yield of oil palm is estimated by GAEZ v4 of IIASA. “very low”: < 1t/ha, “low”: 1-4t/ha, “medium”: 4-6t/ha, “high”: 6-7t/ha, “very high”: ≥ 7t/ha.

Indonesia


Water
Bare Ground
Settlement Area
Paddy Field
Dry Agriculture
Estate Crop
Grassland
Shrub
Plantation Forest
Secondary Forest
Primary Forest
1990 to 2000
2000 to 2011
2011 to 2015
From
To
Area (km²)
10000
20000
30000
40000
50000


Sumatra
Kalimantan
1990 to 2000
2000 to 2011
2011 to 2015
From
To
Water
Bare Ground
Settlement Area
Paddy Field
Dry Agriculture
Estate Crop
Grassland
Shrub
Plantation Forest
Secondary Forest
Primary Forest
Area (km2)
10000
20000
30000
40000
50000

Pooled model, Country

	Natural Forest			Shrub			Dry Agriculture		
	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.
(Intercept)	-63.143	-3.064		-50.173	-2.250		-36.302	-1.640	
Oil palm potential yield	4.90E-04	1.335		1.19E-03	2.989	***	1.28E-03	3.250	***
Plantation 1990	0.011	2.366	**	0.014	2.765	***	0.011	2.239	**
Mill density	-6.64E-04	-0.403		-2.83E-03	-1.577		-3.78E-03	-2.123	**
Access time	7.38E-04	6.727	***	5.34E-04	5.785	***	3.70E-04	3.669	***
Temperature	0.200	2.933	***	0.160	2.165	**	0.112	1.535	
Shortwave radiation	-0.012	-3.849	***	-0.014	-4.430	***	-0.013	-4.061	***
Precipitation	1.85E-04	2.373	**	-2.82E-05	-0.334		-1.41E-04	-1.682	*
AWC	7.35E-04	0.572		-1.48E-03	-1.037		-3.11E-03	-2.254	**
Elevation	4.07E-04	1.469		2.80E-04	0.955		2.18E-04	0.767	
Slope	-0.161	-7.475	***	-0.084	-4.051	***	-0.051	-2.481	**
Source land ratio	8.064	16.058	***	6.944	8.751	***	4.511	7.436	***
Source land ratio^2	-8.004	-13.333	***	-10.048	-7.321	***	-5.418	-7.311	***
Population density	-5.24E-05	-2.690	***	-7.17E-05	-3.315	***	-6.01E-05	-2.762	***
Protected %	-5.16E-03	-1.164		0.014	3.124	***	0.016	3.526	***
Export quantity	6.10E-03	3.719	***	0.010	5.789	***	0.014	7.856	***
LogLik	-3624.051			-3792.253			-3771.070		
AIC	7282.103			7618.507			7576.140		
R2	0.331			0.229			0.156		

Pooled model, Country

	Natural Forest			Shrub			Dry Agriculture		
	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.
(Intercept)	-59.836	-2.903		-44.026	-1.980		-27.891	-1.266	
Oil palm potential yield	4.81E-04	1.312		1.20E-03	3.039	***	1.30E-03	3.310	***
Plantation 1990	0.011	2.362	**	0.014	2.779	***	0.011	2.257	**
Mill density	-6.24E-04	-0.379		-2.74E-03	-1.531		-3.66E-03	-2.071	**
Access time	7.36E-04	6.718	***	5.28E-04	5.740	***	3.58E-04	3.573	***
Temperature	0.189	2.769	***	0.139	1.887	*	0.084	1.152	
Shortwave radiation	-0.012	-3.823	***	-0.014	-4.317	***	-0.012	-3.949	***
Precipitation	1.98E-04	2.546	**	-1.03E-05	-0.123		-1.16E-04	-1.397	
AWC	6.83E-04	0.532		-1.54E-03	-1.084		-3.24E-03	-2.358	**
Elevation	3.78E-04	1.369		2.50E-04	0.857		1.63E-04	0.580	
Slope	-0.161	-7.493	***	-0.086	-4.168	***	-0.053	-2.584	**
Source land ratio	8.066	16.069	***	7.029	8.899	***	4.460	7.394	***
Source land ratio^2	-8.021	-13.368	***	-10.164	-7.449	***	-5.371	-7.289	***
Population density	-5.21E-05	-2.680	***	-7.11E-05	-3.298	***	-6.07E-05	-2.806	***
Protected %	-5.06E-03	-1.142		0.014	3.172	***	0.016	3.594	***
Export value	0.020	3.879	***	0.038	6.965	***	0.050	9.262	***
LogLik	-3623.442			-3784.845			-3759.378		
AIC	7280.883			7603.690			7552.756		
R2	0.332			0.235			0.166		

Sumatra, Shrub, Export value of major estate crops

	Pooled			Spatial Lag			Spatial Error			Durbin		
	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.
Intercept	-63.769	-0.742		-43.679	-0.410		-44.018	-0.380		-34.146	-0.296	
Oil palm potential yield	4.60E-03	2.071	**	4.53E-03	1.479		3.42E-03	1.171		7.00E-04	0.288	
Plantation 1990	-9.42E-03	-1.206		-0.012	-1.138		-0.016	-1.553		-0.015	-1.683	*
Mill density	-5.84E-03	-2.436	**	-5.86E-03	-1.775	*	-6.10E-03	-1.970	**	-5.90E-03	-2.286	**
Access time	3.05E-03	5.359	***	3.41E-03	4.403	***	3.39E-03	4.410	***	3.39E-03	4.907	***
Temperature	0.221	0.774		0.147	0.413		0.159	0.411		0.143	0.370	
Shortwave radiation	-0.048	-2.949	***	-0.032	-1.578		-0.048	-2.011	**	-0.078	-2.581	***
Precipitation	-3.39E-04	-1.576		-3.21E-04	-1.295		-4.11E-04	-1.431		-4.37E-04	-1.297	
AWC	3.13E-03	0.626		3.11E-03	0.454		3.30E-03	0.493		3.33E-03	0.573	
Elevation	1.14E-03	0.879		6.86E-04	0.394		-1.84E-04	-0.107		-1.81E-03	-1.223	
Slope	-0.223	-3.640	***	-0.169	-2.000	**	-0.159	-1.841	*	-0.102	-1.298	
Source land ratio	4.360	1.619		-1.510	-0.474		-0.143	-0.045		3.357	1.162	
Source land ratio^2	-11.290	-2.514	**	-1.420	-0.286		-3.221	-0.663		-6.858	-1.635	
Population density	-3.74E-04	-2.303	**	-3.75E-04	-1.717	*	-4.31E-04	-2.021	**	-3.97E-04	-2.106	**
Protected %	8.04E-03	0.837		2.07E-05	0.002		3.87E-03	0.308		2.07E-03	0.190	
Export Value	0.054	3.492	***	0.041	2.816	***	0.052	2.761	***	0.076	2.119	**
phi				0.221	2.863	**	0.185	2.681	***	0.135	2.345	**
rho							0.261	5.214	***	0.671	11.725	***
lambda				0.232	4.796	***				-0.539	-6.181	***
Log likelihood	-917.529			-897.473			-895.658			-887.505		
AIC	1869.058			1954.947			1951.317			1937.010		
R-squared	0.299											

Sumatra, Dry Agriculture, Export value of major estate crops

	Pooled			Spatial Lag			Spatial Error			Durbin		
	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.
Intercept	61.669	0.634		38.651	0.331		63.750	0.478		66.671	0.503	
Oil palm potential yield	4.41E-03	1.807	*	4.20E-03	1.282		3.71E-03	1.182		1.39E-03	0.538	
Plantation 1990	-0.012	-1.401		-0.016	-1.381		-0.024	-2.105	**	-0.024	-2.575	**
Mill density	-4.40E-03	-1.685	*	-3.42E-03	-0.977		-3.69E-03	-1.118		-4.67E-03	-1.706	*
Access time	1.58E-03	2.444	**	1.70E-03	1.979	**	1.58E-03	1.780	*	1.53E-03	1.945	*
Temperature	-0.202	-0.622		-0.131	-0.335		-0.207	-0.463		-0.204	-0.457	
Shortwave radiation	-0.036	-1.888	*	-0.024	-1.073		-0.038	-1.351		-0.065	-1.856	*
Precipitation	-5.24E-04	-2.178	**	-4.01E-04	-1.490		-3.92E-04	-1.189		-9.90E-05	-0.265	
AWC	-1.47E-03	-0.286		2.47E-03	0.354		2.29E-03	0.329		1.47E-03	0.241	
Elevation	2.71E-04	0.196		1.93E-04	0.107		-6.70E-04	-0.371		-1.95E-03	-1.275	
Slope	-0.157	-2.261	**	-0.094	-1.018		-0.090	-0.942		-0.037	-0.437	
Source land ratio	5.274	2.393	**	4.118	1.470		2.409	0.916		-0.108	-0.051	
Source land ratio^2	-7.397	-2.997	***	-6.090	-1.909	*	-4.576	-1.572		-2.077	-0.919	
Population density	-1.41E-04	-0.760		-7.50E-05	-0.309		-2.19E-04	-0.911		-3.34E-04	-1.612	
Protected %	0.019	1.889	*	0.011	0.866		0.014	1.064		5.86E-03	0.525	
Export Value	0.057	3.350	***	0.034	2.136	**	0.050	2.240	**	0.073	1.571	
phi				0.239	3.169	***	0.207	3.023	***	0.190	2.923	***
rho							0.355	8.027	***	0.763	20.960	***
lambda				0.328	7.515	***				-0.651	-9.252	***
Log likelihood	-945.793			-910.558			-907.576			-889.284		
AIC	1925.586			1981.116			1975.152			1940.569		

Kalimantan, Shrub, Export value of major estate crops

	Pooled			Spatial Lag			Spatial Error			Durbin		
	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.
Intercept	-297.198	-1.336		-254.348	-1.151		-490.488	-2.015	**	-550.644	-2.189	
Oil palm potential yield	-0.011	-1.827	*	-0.012	-1.798	*	-9.06E-03	-1.510		-6.69E-03	-1.325	
Plantation 1990	0.136	2.439	**	0.126	2.154	**	0.097	1.635		0.068	1.209	
Mill density	0.015	0.530		0.011	0.351		8.96E-03	0.338		0.013	0.574	
Access time	1.11E-03	2.885	***	7.22E-04	1.799	*	9.28E-04	2.266	**	1.02E-03	2.627	***
Temperature	0.974	1.316		0.850	1.156		1.622	2.001	**	1.801	2.149	**
Shortwave radiation	0.049	1.904	*	0.028	1.069		0.038	1.446		0.057	2.189	**
Precipitation	-8.13E-05	-0.175		1.17E-04	0.262		5.59E-04	1.040		7.92E-04	1.339	
AWC	-0.012	-1.046		-0.014	-1.170		-0.027	-2.198	**	-0.034	-3.142	***
Elevation	-3.26E-03	-0.415		-3.12E-03	-0.382		5.20E-03	0.678		0.010	1.446	
Slope	0.041	0.117		2.55E-03	0.007		-0.324	-0.943		-0.556	-1.878	*
Source land ratio	9.674	2.428	**	10.141	2.587	***	8.882	2.402	**	7.290	2.248	**
Source land ratio^2	-13.971	-2.039	**	-14.871	-2.298	**	-13.018	-2.072	**	-10.982	-1.952	*
Population density	-2.23E-03	-2.069	**	-3.01E-03	-2.822	***	-2.82E-03	-2.580	***	-2.36E-03	-2.219	**
Protected %	-2.39E-03	-0.072		0.010	0.298		0.010	0.310		1.02E-03	0.040	
Export Value	0.094	3.773	***	0.052	2.334	**	0.071	2.090	**	0.110	1.725	*
phi				0.064	1.061		0.041	0.779		0.026	0.532	
rho							0.394	5.554	***	0.721	10.522	***
lambda				0.352	5.028	***				-0.541	-4.068	***
Log likelihood	-513.259			-502.085			-500.249			-495.733		
AIC	1060.518			1106.170			1102.498			1095.467		

Kalimantan, Dry agriculture, Export value of major estate crops

	Pooled			Spatial Lag			Spatial Error			Durbin		
	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.	$\hat{\beta}$	t-value	sig.
Intercept	-119.182	-0.619		-39.764	-0.238		-235.681	-1.136		72.682	0.497	
Oil palm potential yield	-0.014	-2.564	**	-0.012	-2.456	**	-9.15E-03	-1.940	*	-0.013	-2.823	***
Plantation 1990	0.192	4.180	***	0.185	4.658	***	0.169	3.860	***	0.190	5.019	***
Mill density	0.021	0.925		-1.55E-04	-0.008		0.010	0.512		-5.74E-03	-0.287	
Access time	9.83E-04	2.856	***	7.28E-04	2.442	**	7.86E-04	2.423	**	6.76E-04	2.424	**
Temperature	0.390	0.612		0.139	0.251		0.772	1.123		-0.229	-0.477	
Shortwave radiation	0.033	1.701	*	0.017	1.031		0.028	1.478		0.016	0.975	
Precipitation	-4.21E-04	-1.089		-3.48E-04	-1.040		-2.47E-05	-0.056		-4.74E-04	-1.657	*
AWC	6.20E-03	0.658		4.55E-03	0.558		-2.81E-03	-0.313		7.24E-03	0.981	
Elevation	-0.016	-2.132	**	-0.012	-1.869	*	-6.63E-03	-1.023		-0.015	-2.375	**
Slope	0.493	1.564		0.272	0.999		0.143	0.526		0.330	1.244	
Source land ratio	8.559	3.187	***	8.013	3.447	***	7.588	3.004	***	7.799	3.638	***
Source land ratio^2	-11.085	-3.431	***	-11.086	-3.963	***	-9.701	-3.272	***	-11.206	-4.238	***
Population density	-2.30E-03	-2.855	***	-2.93E-03	-4.194	***	-2.40E-03	-3.151	***	-3.06E-03	-4.554	***
Protected %	-0.033	-1.118		-0.020	-0.793		-0.016	-0.658		-0.022	-0.869	
Export Value	0.145	7.089	***	0.072	4.052	***	0.124	4.189	***	0.056	4.027	***
phi				1.00E-08	NA		1.00E-08	0.039		1.00E-08	0.039	
rho							0.428	5.984	***	-0.283	-1.804	*
lambda				0.446	6.339	***				0.600	6.778	***
Log likelihood	-466.624			-447.650			-452.083			-446.386		
AIC	967.248			997.300			1006.167			996.773		

Conclusion

- Our analysis reveals a ***stepwise process*** of the conversion:

  Forest ⇒ secondary forest ⇒ shrub & dry agriculture ⇒ estate crop

  - More from shrub and dry agriculture as time goes by
  - The main results of secondary forest are shrub, dry agriculture, and estate crop
  - The main results of shrub conversion are dry agriculture, and estate crop
  - The stepwise process: logging firstly convert primary to secondary forest, which is converted to shrub and dry agriculture, and increasing plantation of estate crop largely takes place in shrub and dry agricultural land.

- Export has been a significant drive of estate crop expansion when focusing on shrub and dry-agriculture as the sources
- In Kalimantan, there is a “pecking order” phenomenon when evaluating the effect of potential revenue of oil palm on estate crop expansion into shrub and dry-agricultural areas.