Supplementary Information for:

"Regional air quality impacts of future fire emissions in Sumatra and Kalimantan"

Miriam E. Marlier, Ruth S. DeFries, Patrick S. Kim, David L.A. Gaveau, Shannon N. Koplitz, Daniel J. Jacob, Loretta J. Mickley, Belinda A. Margono, and Samuel S. Myers

Ancillary Datasets for Land Cover Change Model

Soil information was from the Harmonized World Soil Database (HWSD), Version 1.2 (FAO *et al* 2012), which provides the dominant soil type at 30 arc-second resolution and was produced by combining regional and national updates with global soil information from the FAO-UNESCO Soil Map of the World. Sumatra and Kalimantan were characterized by 14 general soil types, which were further differentiated by variations in associated soil types and inclusions. We did not reconcile the soil information with landform types from Margono et al. (2014), as the HWSD dataset contains more detailed information on soil variation, and we found good overall agreement with landform type (Table S1). For example, < 3% of pixels were classified as histosols (organic soils) on the dryland landform type and as acrisols (clay-rich soils) on the peatland landform type.

Elevation and slope information was from the GTOPO30 global digital elevation model (DEM), available at 30-arc second resolution (https://lta.cr.usgs.gov/GTOPO30). GTOPO30 is derived from 8 sources of elevation information. Globally, most of the information used to produce GTOPO30 is from the Digital Terrain Elevation Data (DTED) and Digital Chart of the World (DCW).

River networks were provided by WWF's HydroSHEDS dataset at 30-arc second resolution, based on hydrological data and maps based on derivatives at multiple scales (http://hydrosheds.cr.usgs.gov/index.php).

Industrial-scale oil palm and timber (for wood pulp and paper) concessions were downloaded from the Global Forest Watch (World Resources Institute 2015a, 2015b), which is based on information provided by the Indonesian Ministry of Forestry (http://www.dephut.go.id/index.php).

Protected areas for Kalimantan and Sumatra included national parks, nature reserves, and hydrological reserves as described by Gaveau et al. (2009, 2013). For the future projections, we extended protected areas to include Indonesia's recent moratorium on granting new plantation concessions with version 6 of spatial planning information (http://www.ukp.go.id/informasi-publik/cat_view/20-geospasial) and new protected areas created since 2005.

Datasets delineating logging roads (Sumatra and Kalimantan) and main roads (Kalimantan only) are described in Gaveau et al. (Gaveau *et al* 2014, 2012, 2009) and were used to calculate the distance from each grid cell to roads.

Distance to oil palm mills was calculated using the dataset described in in Gaveau et al. (2013). This data is publicly available from the US EPA (http://www.regulations.gov/#!searchResults;rpp=10;po=0;s=epa-hq-oar-2011-0542; http://www.regulations.gov/#!searchResults;rpp=10;po=0;s=epa-hq-oar-2011-0542%257CWilmar) for mills used by Wilmar International and their competitors.

Table S1. Distribution of 1-km^2 grid cells in Margono et al. (2014) landform dataset, including separate peat delineation (Wahyunto *et al* 2003, 2004), in columns, and detailed soil types from the Harmonized World Soil Database (FAO *et al* 2012), in rows.

a)_Sumatra:

Soil Type	**Dryland**	**Wetland**	**Upland**	**Montane**	**Peat**	**Total**
Acrisols	147,436	9,080	33,719	15,670	2,167	208,072
Andosols	8,224	379	5,074	9,174	0	22,851
Arenosols	4,954	846	0	0	0	5,800
Cambisols	21,300	448	8,824	3,930	8	34,510
Ferralsols	9,686	170	723	171	98	10,848
Fluvisols	21,824	20,112	1,108	108	10,496	53,648
Gleysols	4,022	5,227	44	0	4,078	13,371
Histosols	7,271	15,256	47	0	47,657	70,231
Leptosols	1,080	169	686	277	23	2,235
Lixisols	2,352	97	446	0	0	2,895
Luvisols	5,627	138	1,503	296	0	7,564
Nitisols	1,796	63	234	15	0	2,108
Plinthosols	5,113	473	9	0	48	5,643
Podzols	127	0	226	1,032	87	1,472
Total	240,812	52,458	52,643	30,673	64,662	441,248

b) Kalimantan:

Soil Type	**Dryland**	**Wetland**	**Upland**	**Montane**	**Peat**	**Total**
Acrisols	165,281	3,860	62,031	11,210	1,806	244,188
Andosols	0	0	0	0	0	0
Arenosols	48,028	8,032	1,587	6	3,665	61,318
Cambisols	3,908	299	316	0	31	4,554
Ferralsols	39,951	1,436	9,564	162	577	51,690
Fluvisols	15,316	17,273	541	0	19,037	52,167
Gleysols	3,043	4,718	74	0	13,856	21,691
Histosols	5,726	9,538	177	0	24,108	39,549
Leptosols	0	0	0	0	0	0
Lixisols	13,863	307	2,287	0	70	16,527
Luvisols	1,328	0	764	44	0	2,136
Nitisols	2,358	327	149	0	202	3,036
Plinthosols	0	0	0	0	0	0
Podzols	11,371	8,796	131	0	11,767	32,065
Total	310,173	54,586	77,621	11,422	75,119	528,921

Table S2. Correlation between each input dataset and all others for a) Sumatra and b) Kalimantan at 1-km^2 resolution. Variance Inflation Factor (VIF) values <5 indicate that multicollinearity is low.

a) Sumatra:

Input Dataset	**R**	**VIF**
Elevation	0.64	1.71
Soil	0.33	1.12
Protected Area	0.65	1.72
Concession (Oil Palm + Timber)	0.72	2.05
Slope	0.40	1.19
Distance to Logging Roads	0.32	1.11
Distance to Rivers	0.34	1.13
Distance to Mills	0.69	1.90
Distance to Degraded Forest	0.51	1.35
Distance to Intact Forest	0.63	1.65
Distance to Non-Forest	0.75	2.29
Distance to Plantation	0.68	1.84

b) Kalimantan:

Input Dataset	**R**	**VIF**
Elevation	0.80	2.73
Soil	0.22	1.05
Protected Area	0.58	1.50
Concession (Oil Palm + Timber)	0.69	1.91
Slope	0.28	1.09
Distance to Logging Roads	0.53	1.39
Distance to Rivers	0.22	1.05
Distance to Main Roads	0.89	4.63
Distance to Mills	0.72	2.06
Distance to Degraded Forest	0.50	1.33
Distance to Intact Forest	0.64	1.70
Distance to Non-Forest	0.73	2.17
Distance to Plantation	0.91	6.01

Table S3. Distribution of land cover (in km^2) within legal oil palm and timber industrial concessions (World Resources Institute 2015a, 2015b). Area located within both the non-forest class and legal concession boundary, based on information provided by the Indonesian Ministry of Forestry, is referred to as "plantation" and could represent land that has been cleared for future production, abandoned grassland or shrubland, or is currently in production. Percentage cleared or productive indicates which percentage of legal concession area is non-forest.

a) Sumatra:

	2005	**2010**
Intact Forest	1,054	949
Degraded Forest	20,934	14,765
Non-Forest (Plantation)	55,665	61,939
% Cleared or Productive	72%	80%
% Plantation Area Change		11%

b) Kalimantan:

	2005	**2010**
Intact Forest	1,273	1,146
Degraded Forest	48,346	41,831
Non-Forest (Plantation)	100,790	107,432
% Cleared or Productive	67%	71%
% Plantation Area Change		7%

Table S4. Plantation areas (km^2) for this study and previous maps of plantation extent (Miettinen *et al* 2012, Gunarso *et al* 2013). Comparisons with Miettinen et al. (2012) refer to industrial oil palm and timber (or pulpwood) plantations on peatlands only. Comparisons with Gunarso et al. (2013) combines oil palm, swamp shrub/grassland, and bare soil on all soil types. The agroforest/rubber/timber plantations class from Gunarso et al. (2013) includes small-scale plantings of multiple species with industrial rubber and timber plantations, which makes straightforward comparison with our plantation areas more difficult. However, the inclusion of this class in plantation area for Gunarso et al. (2013) is reflected in the total in parentheses.

		2005		**2010**	
		Sumatra	Kalimantan	Sumatra	Kalimantan
Industrial oil palm + timber; Peatland only	Miettinen	-	-	18,830	3,290
	This Study	15,473	10,390	18,980	12,213
Oil palm + swamp shrub/grassland + bare soil; All soils (With agroforest + rubber + timber)	Gunarso	79,050 (205,840)	42,690 (57,660)	86,180 (206,300)	61,790 (76,710)
Industrial oil palm + timber; All soils	This Study	55,665	100,790	61,939	107,432

Figure S1. Future land cover change projections for *Peat Protection* (as in Figure 3) and *Peat Protection with Leakage*. The leakage scenario assumes that the observed 2005-2010 deforestation and degradation rate in peatlands is added to the lowland rate after all peatlands are conserved. Total cumulative emissions for 2010-2030 increased from 782 to 793 Tg DM (*Peat Protection* to *Peat Protection with Leakage*) in Sumatra and 999 to 1017 Tg DM for Sumatra.

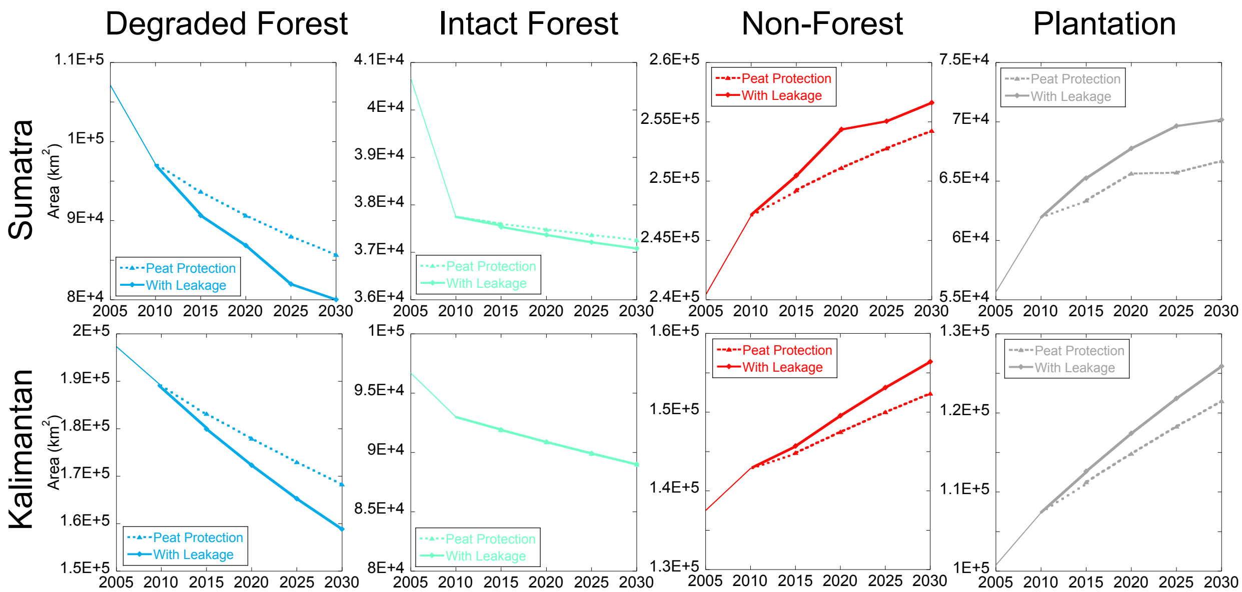


Figure S2. Minimum similarity at multiple window sizes between the observed 2010 land cover map from Margono et al. (2014) and the simulated 2010 map in the BAU scenario. A 27-km window size approximately corresponds to 0.25° at the equator; the similarity between observed and simulated 2010 maps at this resolution was ~95% for both Sumatra and Kalimantan.

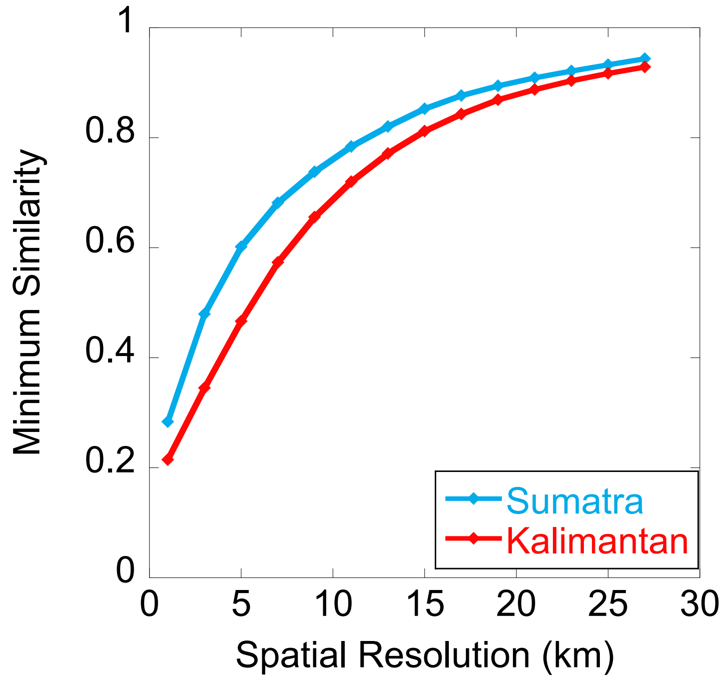


Figure S3. Monthly total emissions (Tg DM) observed from January 2005 to December 2009 for a) peatland, b) lowland, and c) wetland for 6 land cover transitions and 4 stable (non-transitioning) land cover types. Montane and upland emissions were small and are not shown here. Note change of scale in y-axes. d) Observed 2005-2009 area (km^2) for each corresponding land cover transition or stable land cover.

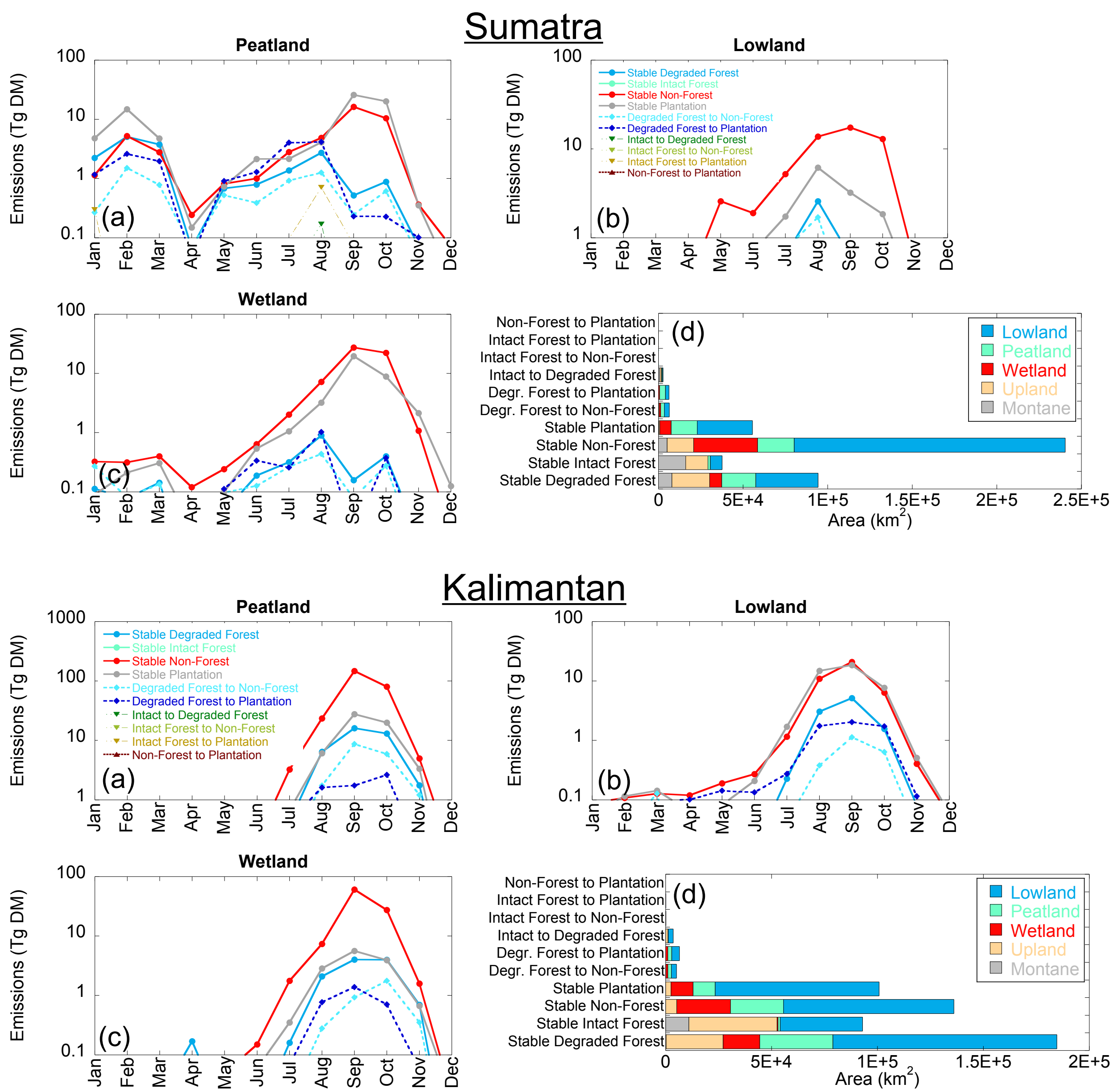


Figure S4. Population distribution used in GEOS-Chem adjoint model calculations (from http://web.ornl.gov/sci/landscan).

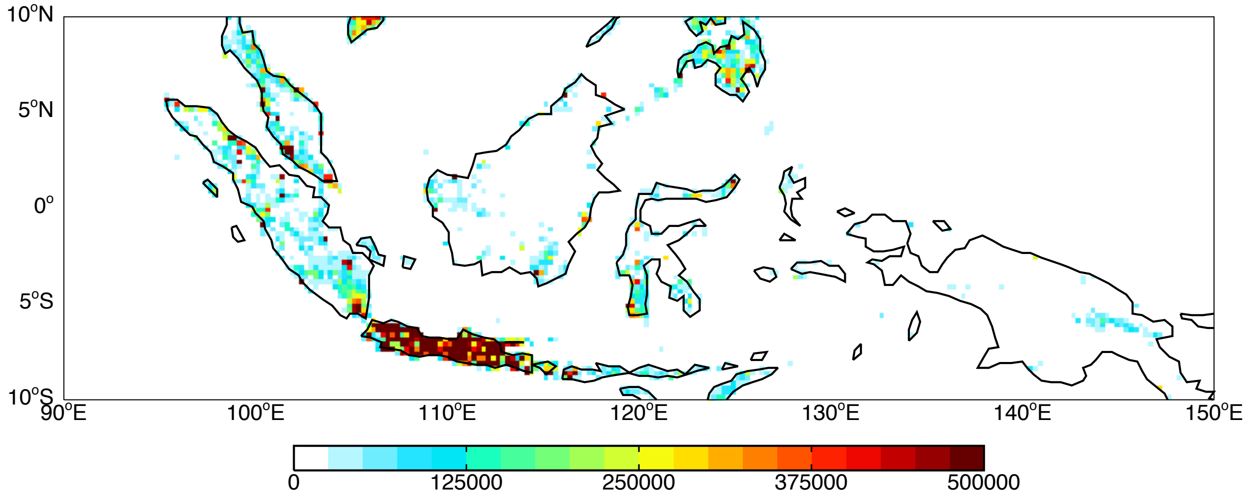
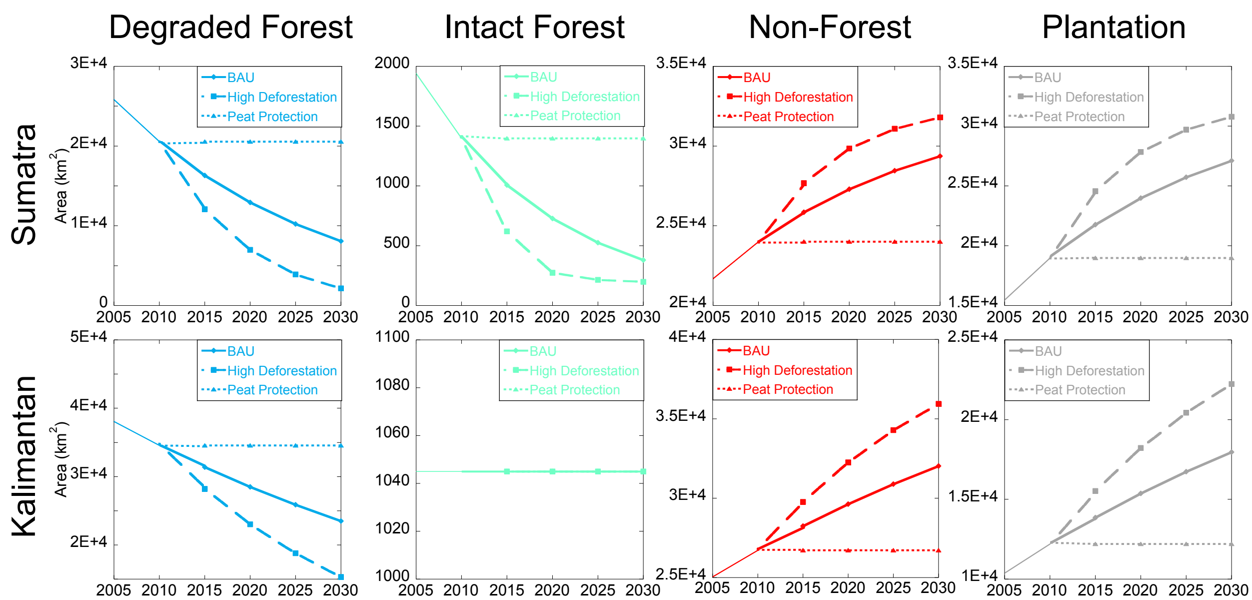


Figure S5. Future areal coverage projections (in km^2) of each land cover type for 2005 to 2030 for Sumatra (top row) and Kalimantan (bottom row) for peatlands only. Three future scenarios include: 1) *BAU*: business-as-usual conditions continue from 2005 to 2010 observations, 2) *High Deforestation*: double the rate of transitions from intact and degraded (logged) forest to non-forest or plantation and intact to degraded (logged) forest, and 3) *Peat Protection*: protect all peatlands from conversion and fire. Thin solid line shows 2005 to 2010 observations from Margono et al. (2014). Note change in scale of y-axes.



References:

FAO, IIASA, ISRIC, ISSACASJRC 2012 *Harmonized World Soil Database (version 1.2)* (FAO, Rome, Italy and IIASA, Laxenburg, Austria)

Gaveau D L A, Kshatriya M, Sheil D, Sloan S, Molidena E, Wijaya A, Wich S, Ancrenaz M, Hansen M, Broich M, Guariguata M R, Pacheco P, Potapov P, Turubanova S and Meijaard E 2013 Reconciling forest conservation and logging in Indonesian Borneo *PLoS ONE* **8** e69887

Gaveau D L A, Sloan S, Molidena E, Yaen H, Sheil D, Abram N K, Ancrenaz M, Nasi R, Quinones M, Wielaard N and Meijaard E 2014 Four decades of forest persistence, clearance and logging on Borneo *PLoS ONE* **9** e101654

Gaveau D, Curran L, Paoli G D, Carlson K, Wells P, Besse-Rimba A, Ratnasari D and Leader-Williams N 2012 Examining protected area effectiveness in Sumatra: importance of regulations governing unprotected lands *Conserv. Lett.* **5** 142–8

Gaveau D, Epting J, Lyne O and Linkie M 2009 Evaluating whether protected areas reduce tropical deforestation in Sumatra *J. Biogeogr.* **36** 2165–75

Gunarso P, Hartoyo M E, Agus F and Killeen T J 2013 *Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea* (www.rspo.org)

Margono B A, Potapov P V, Turubanova S, Stolle F and Hansen M C 2014 Primary forest cover loss in Indonesia over 2000–2012 *Nature Clim. Change* **4** 730–5

Miettinen J, Hooijer A, Shi C, Tollenaar D, Vernimmen R, Liew S C, Malins C and Page S E 2012 Extent of industrial plantations on Southeast Asian peatlands in 2010 with analysis of historical expansion and future projections *GCB Bioenergy* **4** 908–18

Wahyunto S, Rintung and Subagjo H 2004 *Peta Luas Sebaran Lahan Gambut dan Kandungan Karbon di Pulau Kalimantan / Maps of Area of Peatland Distribution and Carbon Content in Kalimantan, 2000-2002.* (Bogor, Indonesia: Wetlands International - Indonesia Programme & Wildlife Habitat Canada (WHC))

Wahyunto S, Rintung and Subagjo H 2003 *Peta Luas Sebaran Lahan Gambut dan Kandungan Karbon di Pulau Sumatera / Maps of Area of Peatland Distribution and Carbon Content in Sumatera, 1990-2002.* (Bogor, Indonesia: Wetlands International - Indonesia Programme & Wildlife Habitat Canada (WHC))

World Resources Institute 2015a *Oil Palm* Online: http://www.globalforestwatch.org

World Resources Institute 2015b *Wood Fiber* Online: http://www.globalforestwatch.org