

Supplementary material for

Spatial correlates of forest and land fires in Indonesia

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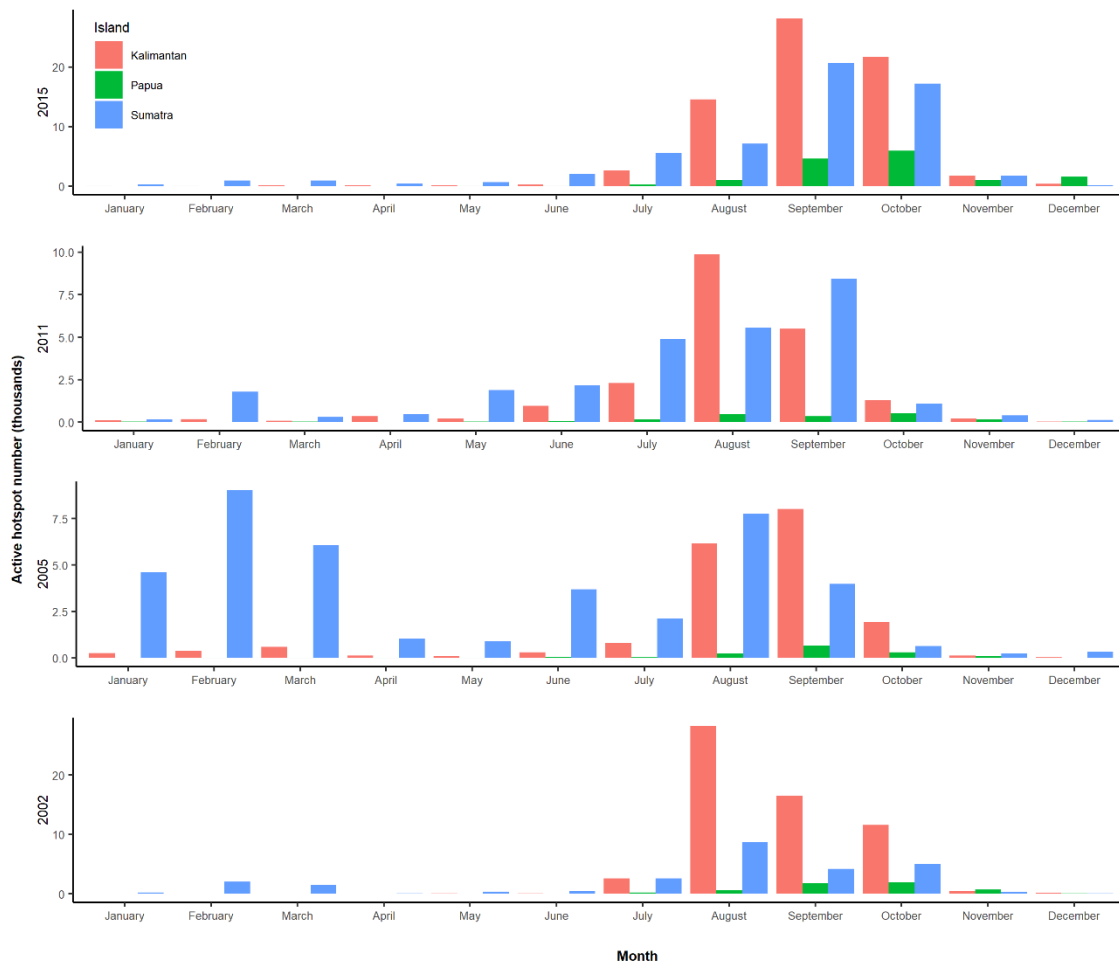


Figure S1. Fire hotspot number (thousands) per month for 2002, 2005, 2011, and 2015.

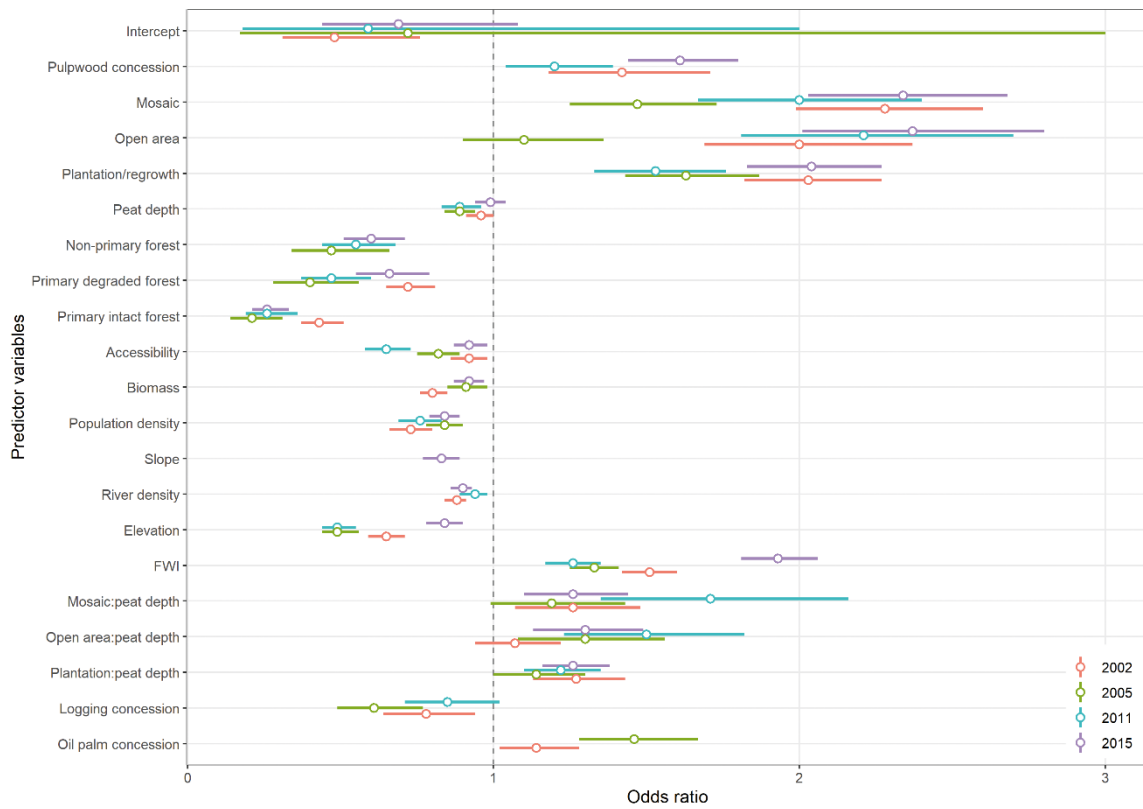


Figure S2. Results of the GLMMs with the detection confidence for fire hotspot set to 80%.

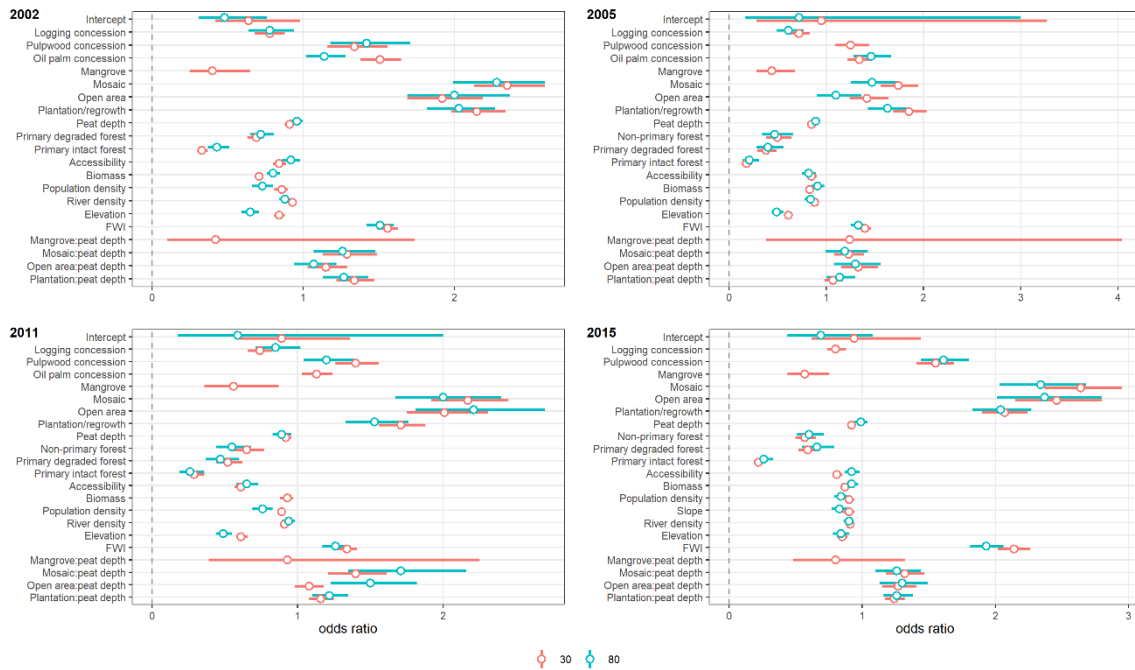


Figure S3. Comparisons of the ORs of predictor variables between the 30% and 80% detection confidence GLMMs.



Figure S4. Intercepts for the random effects of the ZINB models across all four years. Red bars referred to coefficient values less than zero and turquoise bars referred to values greater than zero.

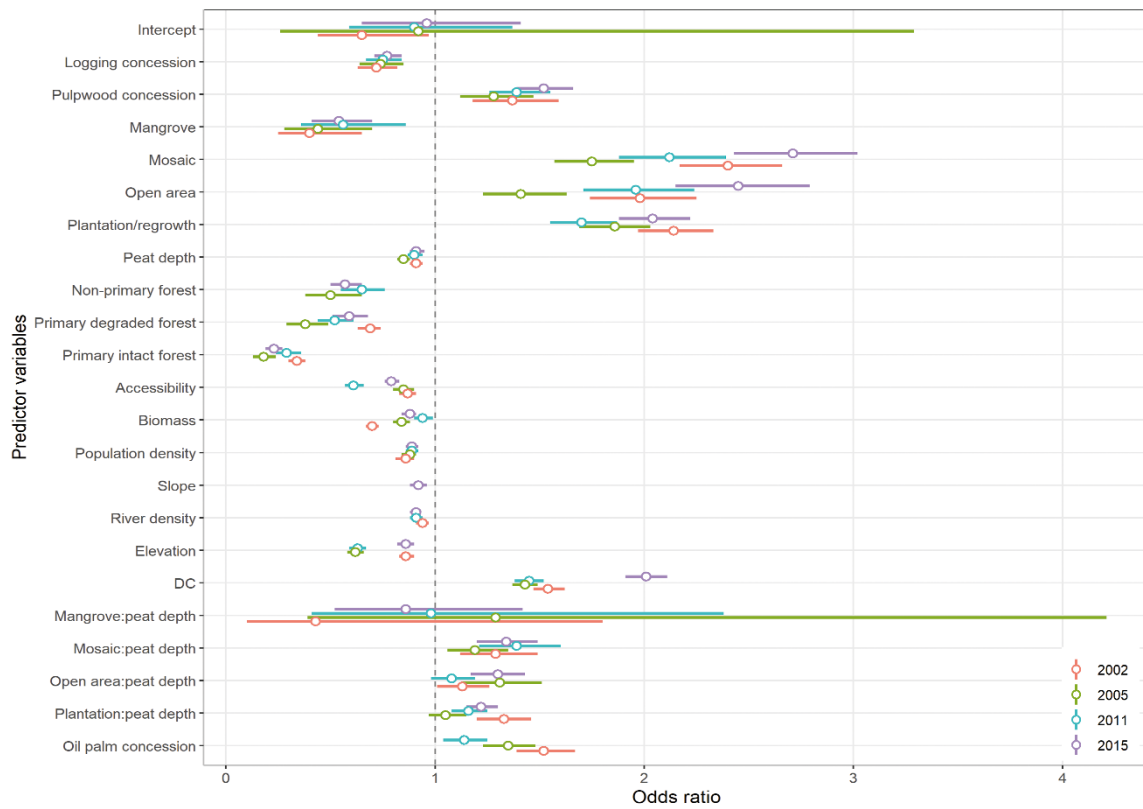


Figure S5. Model estimates from the GLMMs using the DC as the meteorological variable.

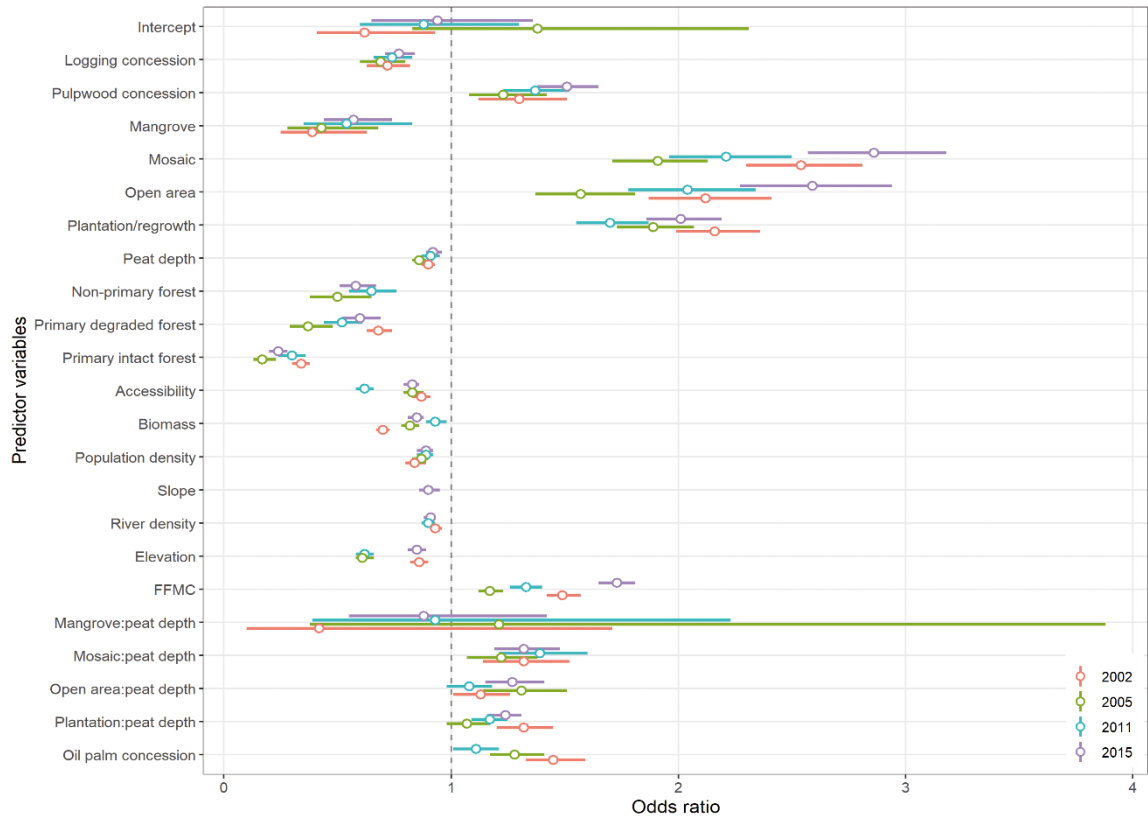


Figure S6. Model estimates from the GLMMs using the FPMC as the meteorological variable.

Table S1. Geographical locations included in the study

Geographic location	Province
Sumatra island	Aceh
	Bangka Belitung
	Bengkulu
	Jambi
	Lampung
	North Sumatra
	Riau
	Riau Islands
	South Sumatra
West Sumatra	
Kalimantan (Indonesian Borneo)	Central Kalimantan
	East Kalimantan
	South Kalimantan
	West Kalimantan
Papua (Western New Guinea)	Papua Province
	West Papua

Table S2. Attributes and sources of the datasets used in the models

Variable	Source	Resolution	Attribute	Data availability
Fire	NASA Fire Information for Resource Management System (FIRMS) MODIS MCD14ML collection 6	1 km	Presence-absence (binary) or fire hotspot count per pixel	2002, 2005, 2011 and 2015
<i>Predisposing conditions</i>				
Land cover	Insular Southeast Asia maps created by the Centre for Remote Imagine, Sensing and Processing (CRISP) of Southeast Asia (Miettinen <i>et al.</i> 2012 <i>b</i> , 2016)	250 m	Water, mangrove, forest, plantation/regrowth, mosaic, open area and urban classes	2000, 2010 and 2015
Aboveground live woody vegetation biomass	Pan-tropical biomass map; GEOCARBON (Avitabile <i>et al.</i> 2016)	1 km	Mg ha ⁻¹	2000-2010
Peat depth	Wetlands International (Wahyunto <i>et al.</i> 2003, 2004, 2006)	N.A.	cm	2000-2002

Elevation	Centre for International Tropical Agriculture, SRTM Digital Elevation Model (Jarvis <i>et al.</i> 2008)	0.000833333° ≈ 90 m	m	2000
Slope	Centre for International Tropical Agriculture, SRTM Digital Elevation Model (Jarvis <i>et al.</i> 2008)	0.000833333° ≈ 90 m	degree	2000
River density	USGS HydroSHEDs river network (Lehner 2013)	N.A.	River line segments/5 km x 5 km pixel	2006

Climatic factors

Fire weather index (annual and June- November)	NASA Goddard Institute for Space Studies, Global Fire WEather Database (GFWED) MERRA-2 (2019)	0.5°×2/3° ≈ 55.5 x 74 km (MERRA-2 and MERRA-2 Corrected) 0.5°×0.5° ≈ 55.5 x 55.5 km (CPC)	N.A.	2002, 2005, 2011, 2015
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Drought code (annual and June- November)	NASA Goddard Institute for Space Studies, Global Fire WEather Database (GFWED) MERRA-2 (2019)	0.5°×2/3° ≈ 55.5 x 74 km (MERRA-2 and MERRA-2 Corrected) 0.5°×0.5° ≈ 55.5 x 55.5 km (CPC)	N.A.	2002, 2005, 2011, 2015
Fine fuel moisture code (annual and June-November)	NASA Goddard Institute for Space Studies, Global Fire WEather Database (GFWED) MERRA-2 (2019)	0.5°×2/3° ≈ 55.5 x 74 km (MERRA-2 and MERRA-2 Corrected) 0.5°×0.5° ≈ 55.5 x 55.5 km (CPC)	N.A.	2002, 2005, 2011, 2015

Ignition factors

Accessibility	Nelson (2008)	0.00833333° ≈ 900 m	Time taken to travel through 1 km pixels to the nearest	2000
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			cities with a population of greater than 50,000 people	
Accessibility	The Malaria Atlas Project, Weiss <i>et al.</i> (2018)	1 km	Travel time to the nearest urban area with a population of at least 1,500 inhabitants per square kilometer or more than 50,000 inhabitants	2015
Logging concessions	Greenpeace (2014), digitized from maps provided by the Ministry of Forestry, Indonesia	N.A.	Presence-absence	2002, 2005, 2011, 2014
Pulpwood concessions	Greenpeace (2014), digitized from maps provided by the Ministry of Forestry, Indonesia	N.A.	Presence-absence	2002, 2005, 2011, 2014
Oil palm concessions	Greenpeace (2014), digitized from agriculture plantation maps provided by the	N.A.	Presence-absence	2014

Planning Department of the Ministry of
Forestry, Indonesia

Primary forest data	Margono <i>et al.</i> (2014)	30 m	Primary degraded forest, primary intact forest, cleared forest, non-primary forest	2000, 2005, 2010, 2012
Population density	Global Population World Grid ver. 4.0 (Center for International Earth Science Information Network 2018)	$0.0416667^\circ \approx 5 \text{ km}$	People/km ²	2000, 2005, 2010, 2015

Other

Island boundary	Database of Global Administrative Areas 3.4 (GADM 2018)		N.A.	N.A.
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Table S3. Land-cover classification

Original and reclassified values for the land-cover data produced by Miettinen *et al.* (2012b, 2016). Lowlands referred to locations with elevation <750 meter above sea level, lower montanes between 750 and 1,500 meter above sea level, and upper montanes >1,500 meter above sea level. Mosaic, open area and plantation/regrowth classes varied in the degree of canopy cover and vegetation types.

2000 and 2005		2010 and 2015	
Original values	Reclassified values	Original values	Reclassified values
Water	Water	Water	Water
Mangrove	Mangrove (Forest)	Mangrove	Mangrove (Forest)
Peat Swamp Forest	Forest	Peat Swamp Forest	Forest
Lowland Forest		Lowland Forest	
Lower Montane Forest		Lower Montane (Evergreen) Forest	
Upper Montane Forest		Upper Montane (Evergreen) Forest	
Plantation/regrowth	Plantation/regrowth	Plantation/regrowth	Plantation/regrowth

Large-scale palm
plantation

Lowland Mosaic

Mosaic

Lowland Mosaic

Mosaic

Montane Mosaic

Montane Mosaic

Lowland Open

Open area

Lowland Open

Open area

Montane Open

Montane Open

Urban

Urban

Urban

Urban

Table S4. Forest cover loss classification

Original and reclassified values for forest cover loss (Margono *et al.* 2014). Primary forest was defined as forest with at least 30% cover per Landsat pixel, had not been disturbed in the last 30 years and were at least 5 ha. Intact primary forests covered an area of at least 50,000 ha with no visible signs of anthropogenic disturbances. Degraded primary forest contained signs of selective logging, fragmentation and other human disturbances in addition to partially open canopy.

Original classification	2000	2005	2010	2012
No change of primary degraded forest from 2000-2012	Primary degraded forest	Primary degraded forest	Primary degraded forest	Primary degraded forest
No change of primary intact forest from 2000-2012	Primary intact forest	Primary intact forest	Primary intact forest	Primary intact forest
No change of non-primary forest from 2000-2012	Non-primary forest	Non-primary forest	Non-primary forest	Non-primary forest
Primary intact, cleared 2005	Primary intact forest	Cleared forest	Cleared forest	Cleared forest
Primary intact, cleared 2010	Primary intact forest	Primary intact forest	Cleared forest	Cleared forest
Primary intact, cleared 2012	Primary intact forest	Primary intact forest	Primary intact forest	Cleared forest

Primary intact, degraded 2005	Primary intact forest	Primary degraded forest	Primary degraded forest	Primary degraded forest
Primary intact, degraded 2010	Primary intact forest	Primary intact forest	Primary degraded forest	Primary degraded forest
Primary intact, degraded 2012	Primary intact forest	Primary intact forest	Primary intact forest	Primary degraded forest
Primary degraded, cleared 2005	Primary degraded forest	Cleared forest	Cleared forest	Cleared forest
Primary degraded, cleared 2010	Primary degraded forest	Primary degraded forest	Cleared forest	Cleared forest
Primary degraded, cleared 2012	Primary degraded forest	Primary degraded forest	Primary degraded forest	Cleared forest
Primary intact degraded 2005, cleared 2010	Primary intact forest	Primary degraded forest	Cleared forest	Cleared forest
Primary intact degraded 2005, cleared 2012	Primary intact forest	Primary degraded forest	Primary degraded forest	Cleared forest
Primary intact degraded 2010, cleared 2012	Primary intact forest	Primary intact forest	Primary degraded forest	Cleared forest

Table S5. Spatial characteristics of fire pixels

Spatial characteristics of fire pixels grouped by geographic location for the categorical predictor variables. Percentage of total fire pixels for each factor level was calculated by dividing the number of pixels in that factor level by the total fire pixels in the island.

Environmental variable	Sumatra (2002)		Kalimantan (2002)		Papua (2002)	
	Fire pixel count	% of total pixels	Fire pixel count	% of total pixels	Fire pixel count	% of total pixels
Total fire pixels (n = 16,231)	5,854	36.07	8,871	54.65	1,506	9.28
<i>Concession</i>						
Pulpwood	344	5.88	416	4.69	39	2.59
Logging	38	0.65	394	4.44	36	2.39
Oil palm	562	9.60	2,706	30.50	83	5.51
<i>Forest cover</i>						
Primary degraded forest	754	12.88	2,239	25.24	531	35.26
Primary intact forest	166	2.84	399	4.50	124	8.23

Non-primary forest	4,864	83.09	6,138	69.19	813	53.98
Cleared forest	-	-	-	-	-	-

Land-cover

Water	29	0.50	50	0.56	24	1.59
Mangrove	40	0.68	85	0.96	7	0.46
Forest	894	15.27	2,414	27.21	569	37.78
Plantation/regrowth	2,687	45.90	3,437	38.74	74	4.91
Mosaic	1,375	23.49	1,875	21.14	636	42.23
Open area	790	13.50	976	11.00	151	10.03
Urban	6	0.10	5	0.06	0	0

Sumatra (2005)

Kalimantan (2005)

Papua (2005)

Total fire pixels	5,667	47.23	5,732	47.77	599	4.99
(n = 11,998)						

Concession

Pulpwood	493	8.70	326	5.69	12	2.00
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Logging	32	0.56	366	6.39	4	0.67
Oil palm	687	12.12	1835	32.01	42	7.01
<i>Forest cover</i>						
Primary degraded forest	899	15.86	1,519	27.02	202	33.72
Primary intact forest	168	2.96	237	4.13	46	7.68
Non-primary forest	4,381	77.31	3,863	67.39	351	58.60
Cleared forest	219	3.86	113	1.97	0	0
<i>Land-cover</i>						
Water	24	0.42	34	0.59	5	0.83
Mangrove	26	0.46	37	0.65	4	0.67
Forest	1162	20.50	1,585	27.65	163	27.21
Plantation/regrowth	2498	44.08	2,492	43.48	44	7.35
Mosaic	1338	23.61	1,118	19.50	286	47.75
Open area	614	10.83	464	8.09	97	16.19
Urban	5	0.09	2	0.03	0	0

	Sumatra (2011)		Kalimantan (2011)		Papua (2011)	
Total fire pixels (n = 12,798)	5,919	46.25	6,200	48.45	679	5.31
<i>Concession</i>						
Pulpwood	897	15.15	748	12.06	59	8.69
Logging	88	1.49	628	10.13	7	1.03
Oil palm	519	8.77	1,857	29.95	40	5.89
<i>Forest cover</i>						
Primary degraded forest	860	14.53	1,453	46.87	191	28.13
Primary intact forest	169	2.86	182	2.94	33	4.86
Non-primary forest	4,331	73.17	4,195	67.66	434	63.92
Cleared forest	495	8.36	306	4.94	1	0.15
<i>Land-cover</i>						

Water	35	0.59	33	0.53	5	0.74
Mangrove	28	0.47	32	0.52	0	0
Forest	692	11.69	1,286	20.74	141	20.77
Plantation/regrowth	3,083	52.09	2,990	48.23	72	10.60
Mosaic	1,183	19.99	1,062	17.13	290	42.71
Open area	903	15.26	779	12.56	139	20.47
Urban	8	0.14	2	0.03	0	0

	Sumatra (2015)		Kalimantan (2015)		Papua (2015)	
Total fire pixels (n = 18,175)	6,651	36.59	9,097	50.05	2,427	13.35

Concession

Pulpwood	1,128	16.96	1,348	14.82	233	9.60
Logging	115	1.73	1,254	13.78	149	6.14
Oil palm	456	6.86	2,407	26.46	177	7.29

Forest cover

Primary degraded forest	1,011	15.20	2,478	27.24	894	36.84
Primary intact forest	139	2.09	227	2.50	343	14.13
Non-primary forest	4,785	71.94	5,733	63.02	1,098	45.24
Cleared forest	636	9.56	549	6.03	29	1.19

Land-cover

Water	53	0.80	113	1.24	73	3.01
Mangrove	39	0.59	93	1.02	39	1.61
Forest	637	9.58	2,146	23.59	1,034	42.60
Plantation/regrowth	4,127	62.05	4,683	51.48	222	9.15
Mosaic	1,019	15.32	1,151	12.65	732	30.16
Open area	703	10.57	864	9.50	278	11.45
Urban	21	0.32	8	0.10	0	0

Table S6. GLMM models evaluation

Three different metrics were calculated, the AUC, Brier Score and R^2 performed on the full dataset. R^2_m refers to the marginal R^2 , that is, the percentage of variance explained by the fixed effects. R^2_c refers to the conditional R^2 , or the variance explained by the overall model.

Years	AUC	Brier Score	Delta		Theoretical	
			R^2_m	R^2_c	R^2_m	R^2_c
30% fire hotspot confidence detection models						
2002	0.86	0.15	0.29	0.40	0.32	0.45
2005	0.83	0.16	0.21	0.42	0.24	0.47
2011	0.83	0.16	0.30	0.39	0.34	0.44
2015	0.84	0.16	0.33	0.42	0.37	0.47
80% fire hotspot confidence detection models						
2002	0.85	0.16	0.25	0.37	0.28	0.42
2005	0.82	0.17	0.20	0.43	0.23	0.50
2011	0.82	0.17	0.25	0.43	0.29	0.50
2015	0.82	0.17	0.27	0.37	0.31	0.42

Table S7. ZINB models evaluation

	RMSE	MAE	MSE
2002	5.53	1.87	30.57
2005	7.15	1.47	51.17
2011	3.40	1.17	11.57
2015	9.51	3.05	90.40