Supporting Online Materials for Curran *et al.* (RE 1091714)

Materials and Methods

1. Field Studies and GIS Data Collection

Field studies:
Building on our long-term ecological studies of vertebrates and dipterocarp dynamics in West Kalimantan in GPNP (1985-2000), Bukit Baka National Park (1991-1993, 1999-2002) and WWF-Betung Kerihun National Park (1996-2003), we conducted field surveys in five lowland protected areas (>100 km^2), 18 timber concessions, three oil palm plantations and interviews and visits within ~23 villages near PAs (1999-2002). Aerial reconnaissance surveys (2000-2001) over Gunung Palung National Park, Gunung Nuit Nature Reserve, and Muara Kendawangan Nature Reserve confirmed deforestation in and around protected areas. Community land use mapping and interviews were conducted with our local partner NGOs (WWF-BKNP KALBAR, Biodamar, YPPN and Titian) from 1999-2003.

GIS data:
The baseline PA dataset was developed from the Consensus Forest Land Use plan (*Tata Guna Hutan Kesepakantan*) implemented in 1985 by the Indonesian Ministry of Forestry Regional Physical Planning Programme for Transmigration (RePPProT; *S1*). Other GIS datasets used in this analysis were compiled from human population censuses (1971-2001), infrastructure (1985-2002), timber concessions (1970-2003), plantations (1992-2002), transmigration (1983-2000) and linked wherever possible to land cover and land use maps digitized from several sources (e.g., Ministry and Regional Forestry; Ministry and Regional Dept. of Agriculture, Ministry and Regional Dept. of Plantations, Parks and Conservation (PKA/PHPA), RePPProT, BAKOSURTANAL, Ministry of Agriculture, and the Land Use Planning and Development Agency (BAPPEDA-KALBAR; *S2*). Individual timber and plantation company work plans with maps were also acquired as well as protected area management plans developed by NGOs and international donor projects.

2. Remote Sensing Methods

The remote sensing methods used in the nested analysis of forest loss within protected areas are described as follows: i) detailed case study of West Kalimantan's Gunung Palung National Park (GPNP) and its surrounding 10 km buffer; ii) 2001-era West Kalimantan province; iii) 2001-era Kalimantan region.

GPNP Analysis: Forest / non-forest supervised classifications (*S3*) were produced from six co-registered Landsat TM/ETM+ images (1988, 1994, 1997, 1999, 2001, 2002; Path 121 Row 61). Forest refers to dipterocarp forest, <500 m a.s.l. with >80% canopy closure (assessed by comparing the 2002 ETM+ forest cover classification with a map of percent tree cover derived from a 2002 Ikonos image). All TM classifications were based on

bands 3-5 and 7; bands 1 and 2 were excluded from the analysis to reduce the effects of atmospheric attenuation (*S4*). GPNP supervised classification results were manually edited via visual interpretation where necessary (e.g., areas of thin haze). Classifications were overlaid within a GIS to produce the cumulative forest loss maps.

An error matrix-based accuracy assessment (*S5, S6*) was performed for part of the 28 August 2002 classification based on independent reference data developed from an Ikonos image (26 May 2002). Within Ikonos bounds, overall accuracy for forest / non-forest (assessed using 80% definition of forest cover) = 86%, with no user or producer class accuracy <74%. Two additional Ikonos images (6 July and 26 May 2002) and field visits confirmed areas planted with oil palm (non-forest) to the northeast of GP. Our 2002 digital classification of GPNP and buffer region were further validated by GPS foot and aerial surveys (March 2000 to August 2002) that documented illegal logging and clearance within GPNP: 69% of 106 compiled GPS points were classified as non-forest; only 2 GPS points were >30 m from TM-classified non-forest.

West Kalimantan Analysis: As with previous large-scale studies of deforestation in the tropics (*S7, S8*), our West Kalimantan analysis is based on visual interpretation of remotely sensed images. First, a baseline map of protected lowland forest areas was created from best-available map sources (described in Part 1 above). Plantation and concession lands, peat, mangrove, water catchment areas, inundated swamps and land >500 m a.s.l. were excluded. Within this baseline, forest and non-forest classes were digitized on-screen via visual interpretation of 17 Landsat ETM+ false-color composite images (1999-2002; referred to as a "2001" assessment in the text). To minimize bias, the analysis was shared between two interpreters collaborating at the same location. Non-forest includes bare soil, scrub/shrub, agricultural land, cleared patches, logging roads and associated logging fronts, skid trails, log loading decks. Visual interpretation allowed classification except in regions of thick haze or cloud, which were considered forested. Interpretation was aided by reference to 7 Ikonos (1 m and 4 m) scenes and expert local knowledge. To discern individual fragments, a 500 m inter-fragment connectance rule was applied.

The results of the visual and digital classifications of the 28 August 2002 image were compared for the Gunung Palung fragment (overall correspondence = 83%). GPS foot and aerial surveys documenting illegal logging within Gunung Palung National Park (March 2000 to August 2002) support our visual interpretation of the Gunung Palung fragment: 51% of 55 compiled GPS points fell within the non-forest category detected on TM. Only 7 GPS points (13%) were >158 m from TM-interpreted non-forest; 3 of these were collected during an aerial survey. In March 2003, two aerial surveys were conducted over 19 forest fragments in the West-Central Kalimantan border region. Non-forest / forest delineated along flight segments corresponded well to our TM visual interpretation [overall correspondence of 87.5% (n = 16) and 85.7% (n = 21), with no user or producer accuracy <77.8%]. The lengths of the two surveys (within lowland protected areas and good visibility conditions) totaled 300 km and 457 km.

Logging roads were visually interpreted within 10 WCMC protected areas (>100 km^2) within available ETM+ coverage (i.e., eight PAs in West Kalimantan and two in Central Kalimantan); total length per PA calculated in a GIS (Table S1).

We assessed for possible bias between the two interpreters who delimited remnant lowland protected forest for the West Kalimantan analysis. The assessment was conducted on a stratified random sample of 14 polygons representing 27% of the baseline area considered in the West Kalimantan analysis. Consistency between the independent interpretations of forest cover was assessed both by linear regression and by measures of agreement derived from an error matrix. Results of this independent assessment suggest low bias (slope of regression line = 0.9718, $r^2 = 0.99$) and strong correspondence (mean overall correspondence = 97%, with no mean user or producer accuracy <82%). For the actual West Kalimantan analysis, bias is expected to be lower, as the two analysts consulted regularly during image interpretation.

Kalimantan analysis: Lowland forest within Kalimantan's World Conservation Monitoring Centre PAs was visually interpreted from 17 MODIS images of Kalimantan (250 m resolution; 1-7 scenes per fragment; 25 February 2001 to 1 July 2002; referred to as a "2001" assessment in the text). A baseline lowland forest map was created using a USGS Digital Elevation Model (1 km) and WWF Ecoregions map. To discern individual fragments, a 1 km inter-fragment connectance rule was applied. One of the analysts interpreted all images, obviating the need for bias analysis. Accuracy assessments of eleven MODIS-mapped fragments (using the visually interpreted Landsat ETM+ as reference data) indicate a mean overall correspondence of 91.2% of detecting forested areas within GIS-delineated protected areas ($r^2 = 0.99$).

References and Notes

S1. RePPProT compiled aerial, ground and satellite-based surveys of land use and form, soil, forest types and condition in 1984-5.

S2. BAPPEDA-KALBAR. (Regional Development Planning Agency). *The Development Study On Comprehensive Regional Development Plan for the Western part of Kalimantan*. (Vols. 1-5, JICA and BAPPENAS, Indonesia, March 1999).

S3. T. M. Lillesand, R. W. Kiefer, *Remote Sensing and Image Interpretation*. (John Wiley and Sons, NY, ed. 4, 1999).

S4. G. M. Foody, G. Palubinskas, R. M. Lucas, P. J. Curran, M. Honzak, *Remote Sens. Env*. **55**, 205 (1996).

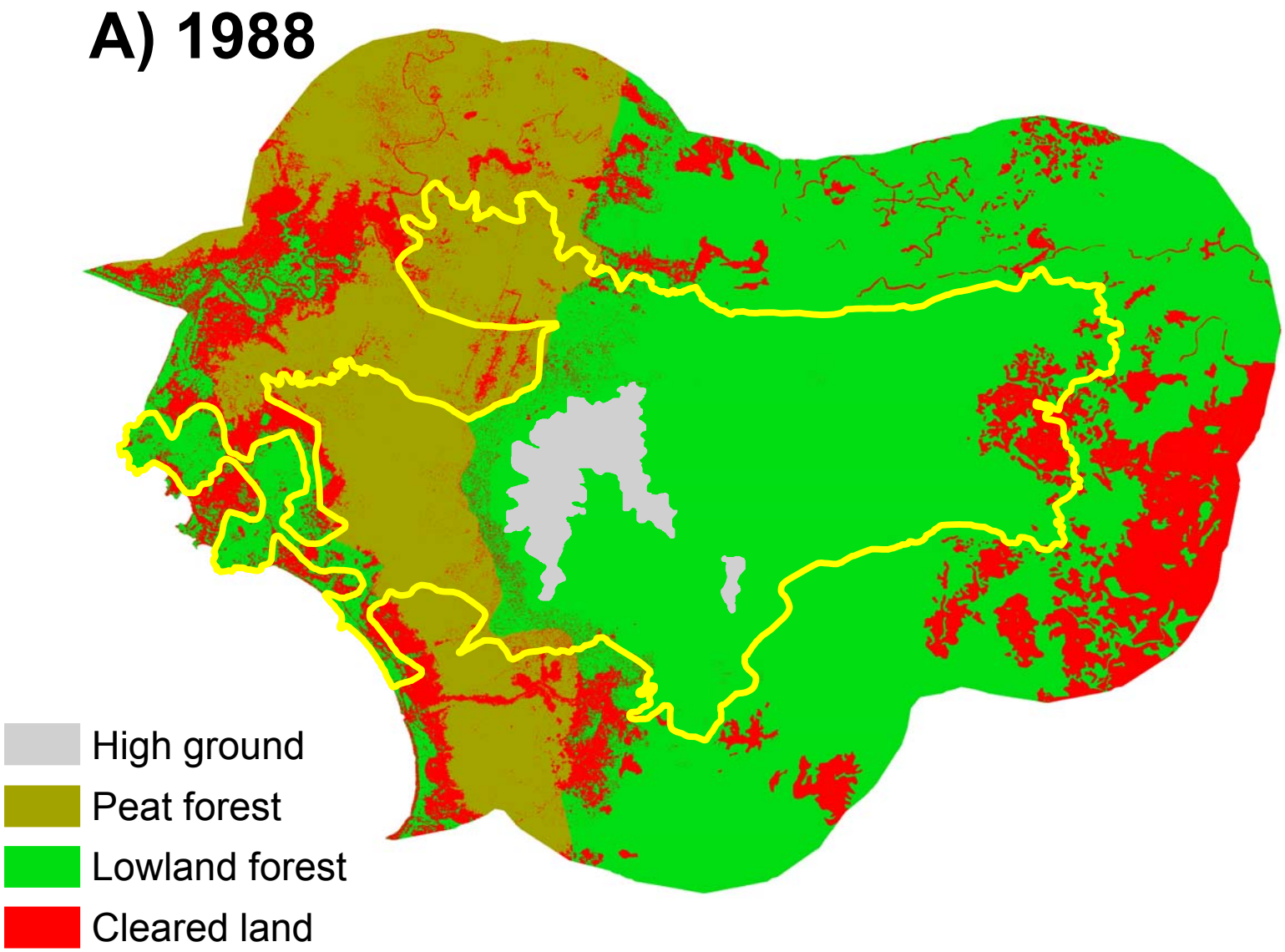
S5. R. G. Congalton, K. Green, *Assessing the Accuracy of Remotely Sensed Data*. (CRC Press, Florida, 1999).

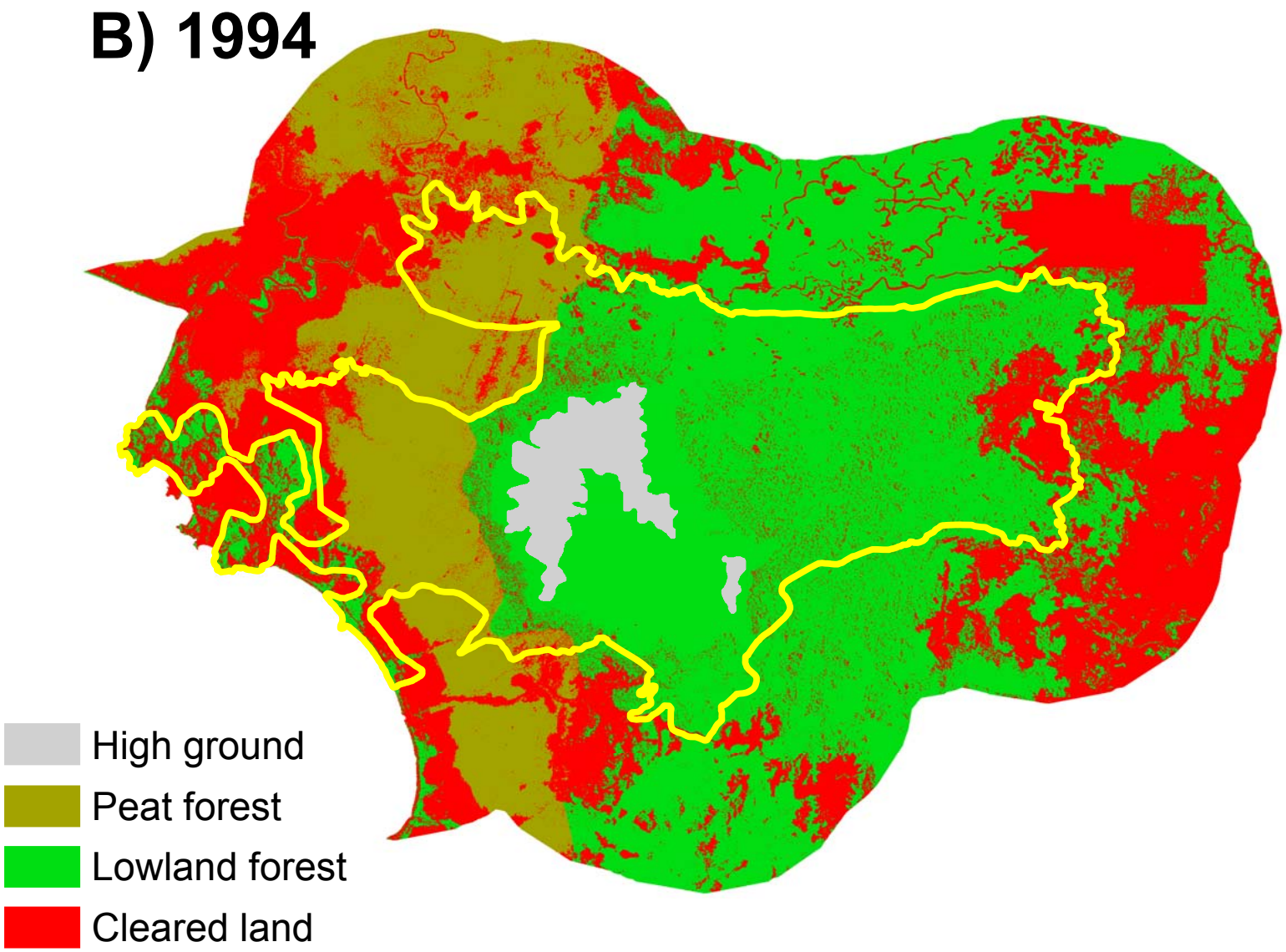
S6. G. M. Foody, *Remote Sens. Env.* **80**, 185 (2002).

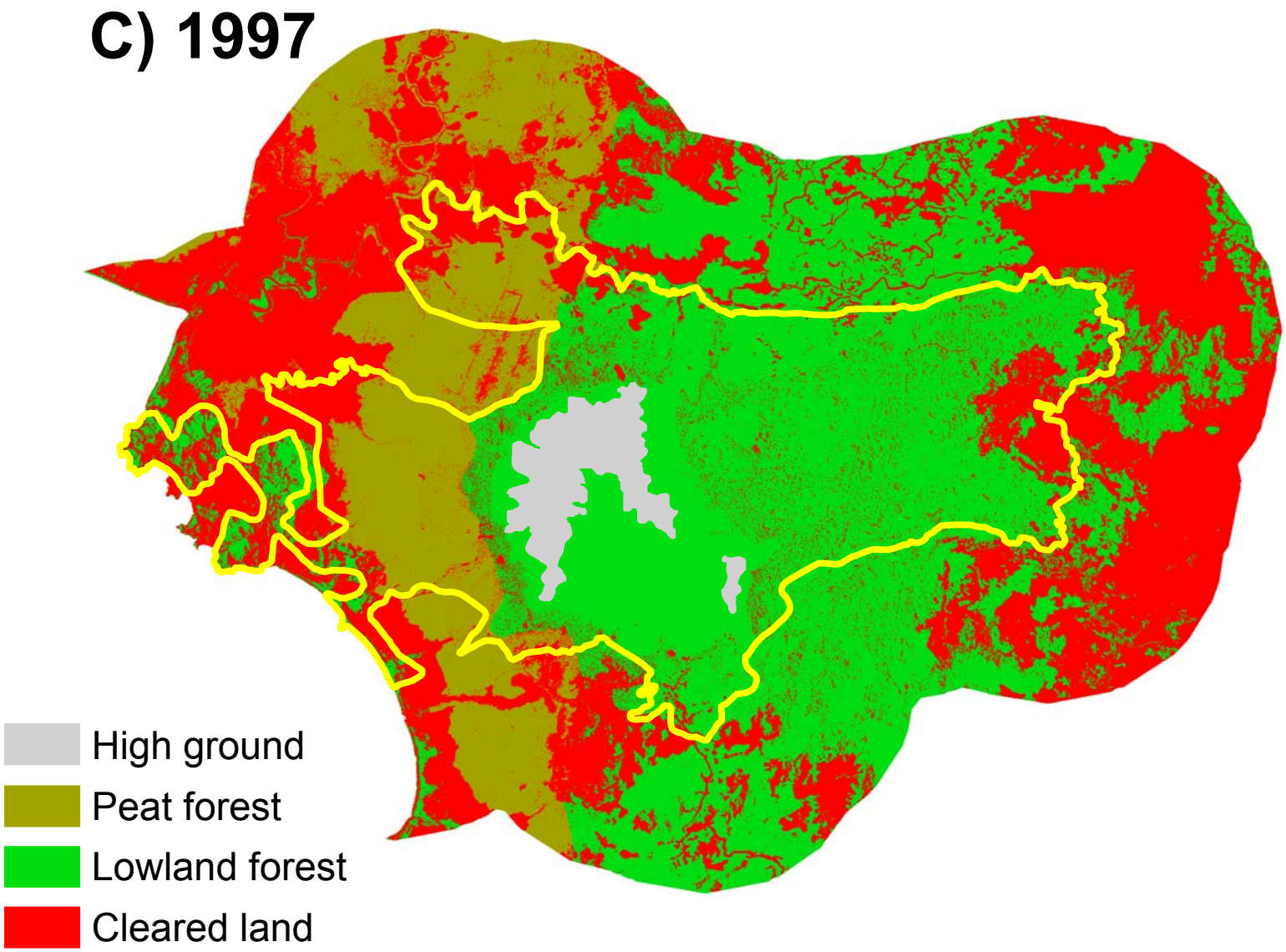
S7. D. Skole, C. Tucker, *Science* **260**, 1905 (1993).

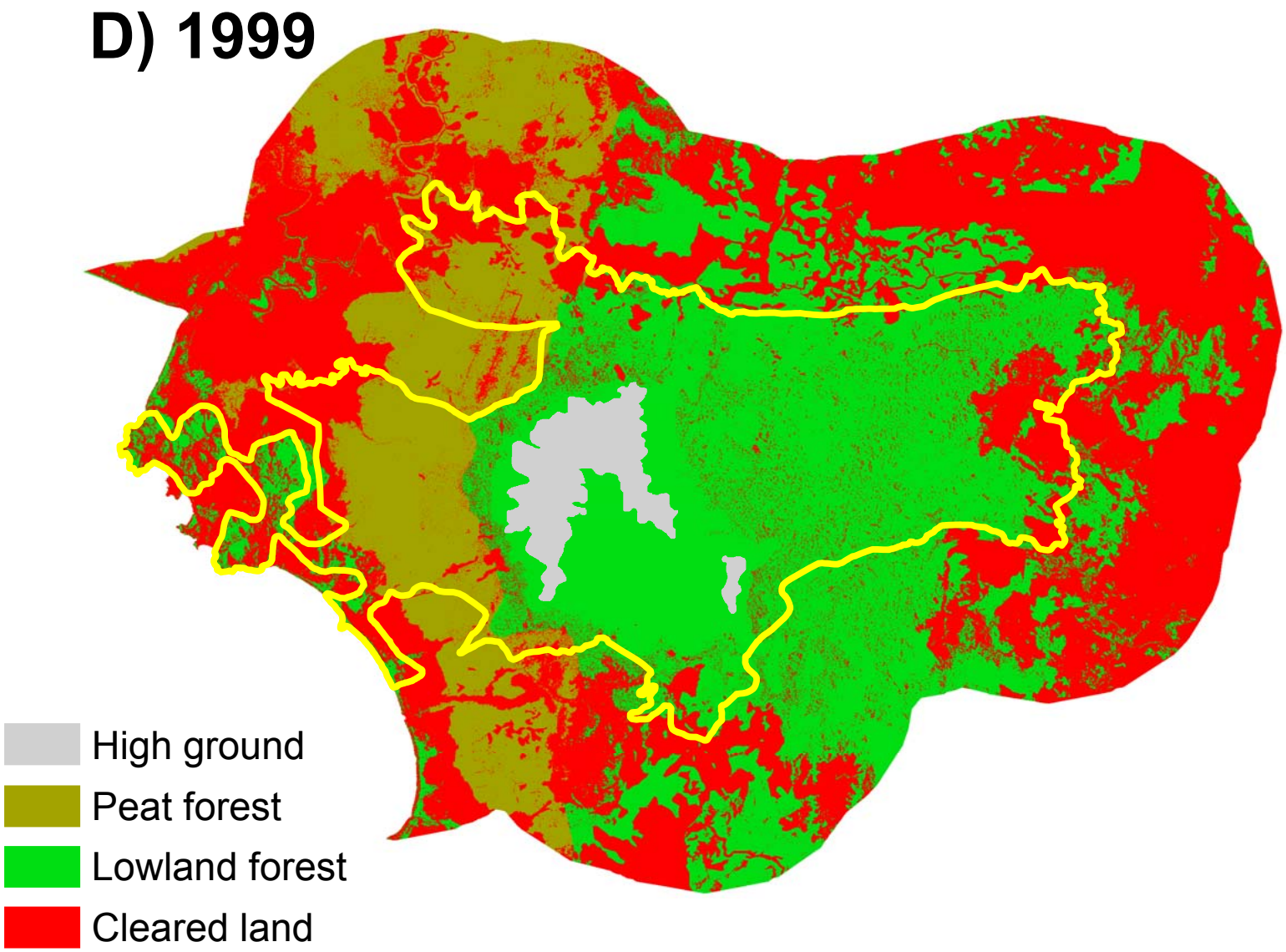
S8. F. Achard *et al*., *Science* **297**, 999 (2002).

Fig. S1. Cumulative forest loss within the Gunung Palung National Park (GPNP) park boundary (yellow) and its surrounding 10 km buffer. Forest/non-forest classifications are based on a Landsat TM time-series: A) 1988, B) 1994, C) 1997, D) 1999, E) 2001, F) 2002.

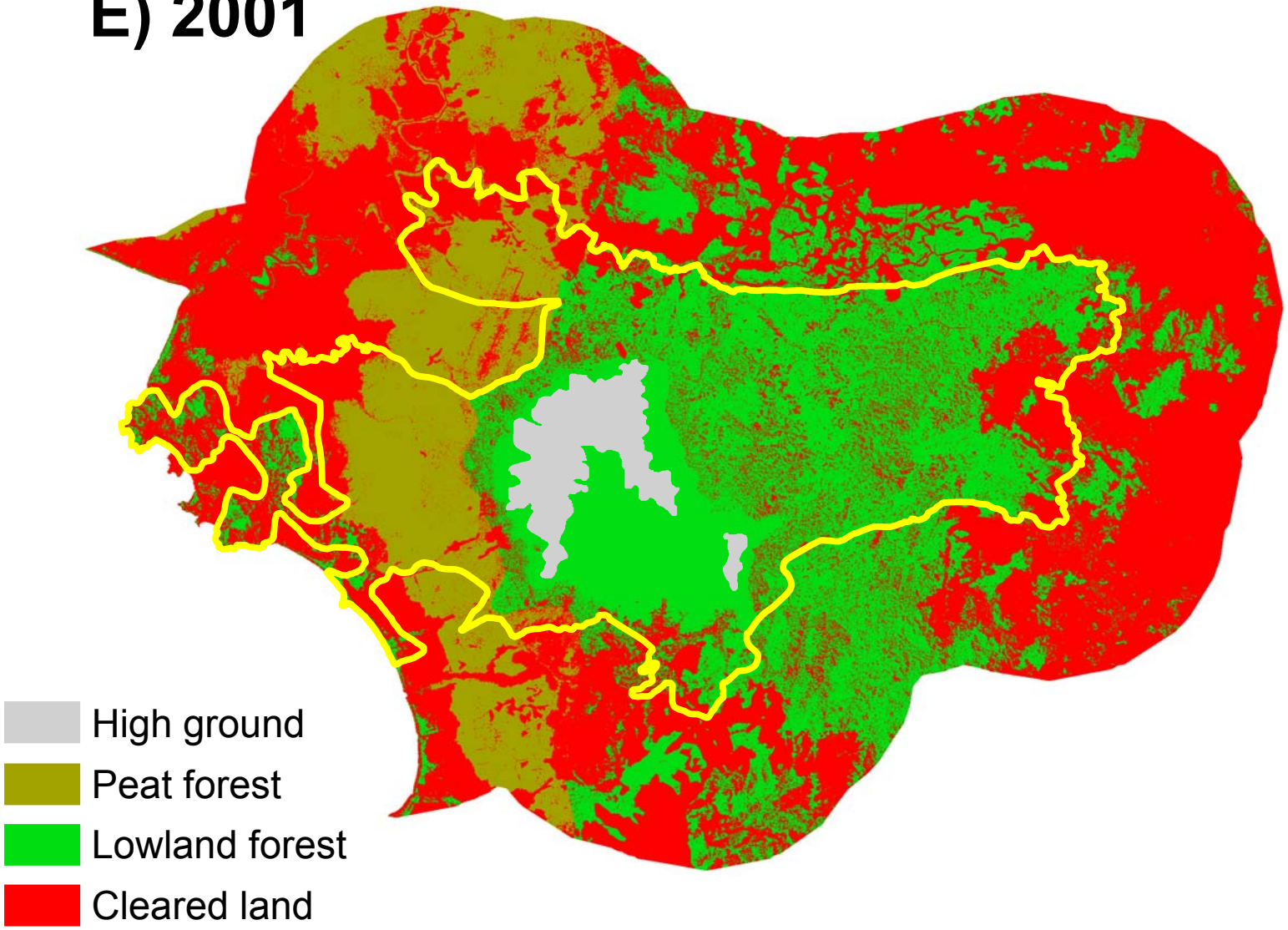



B) 1994
High ground
Peat forest
Lowland forest
Cleared land


C) 1997
High ground
Peat forest
Lowland forest
Cleared land


D) 1999
High ground
Peat forest
Lowland forest
Cleared land

E) 2001



F) 2002

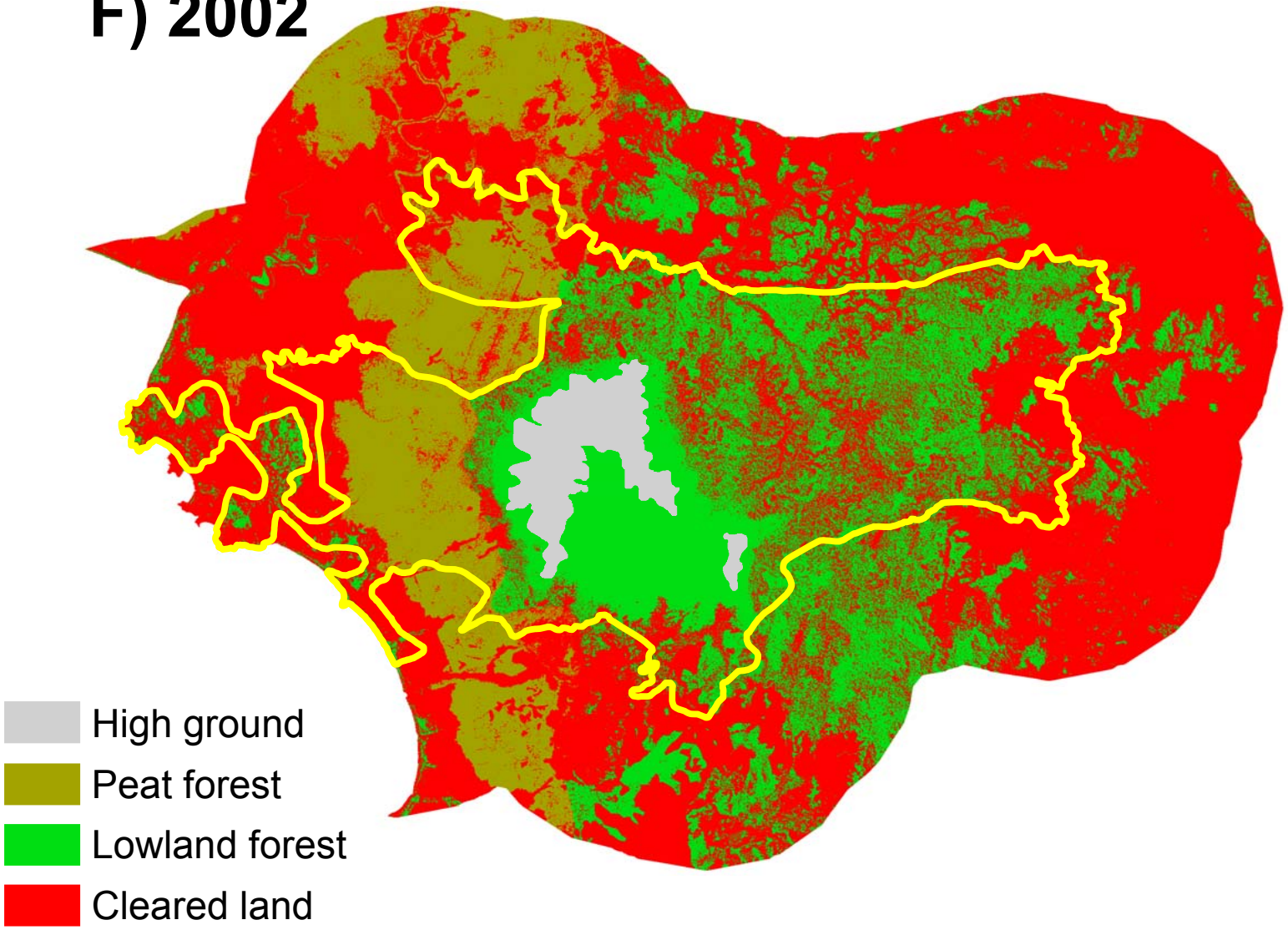


Fig. S2. Loss of protected lowland forest in West Kalimantan. (A) In 1985, protected lowland dipterocarp forest covered ~29,360 km^2 according to best-available maps (PA status updated from 1999 spatial planning map). BK = Betung Kerihun, DS = Danau Sentarum, BB = Bukit Baka, GP = Gunung Palung, MK = Muara Kendawangan. (B) In 2001, ~10,900 km^2 of protected lowland dipterocarp forest remained in West Kalimantan according to our Landsat TM/GIS analysis. Only 16 forest fragments are >100 km^2 and considered viable for large vertebrates.

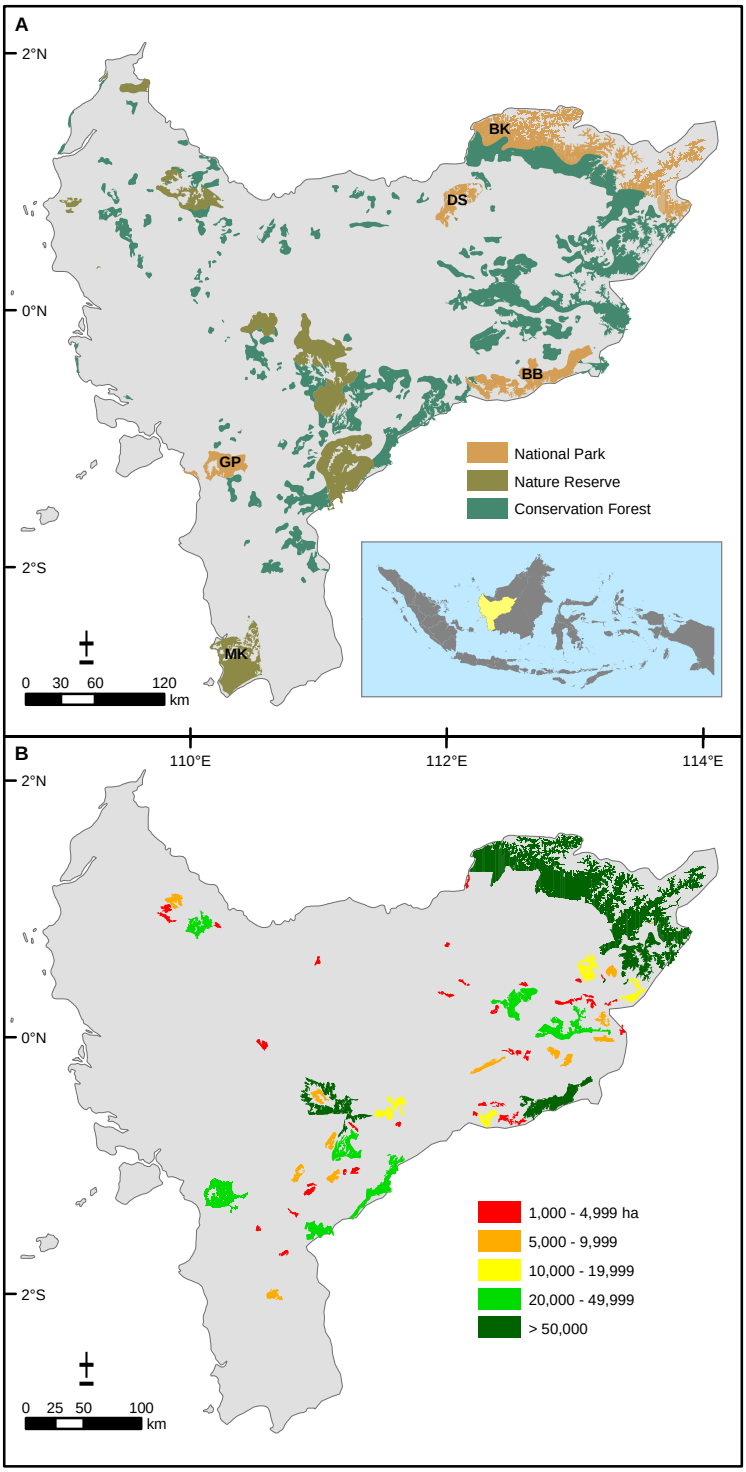


Fig. S3. Observed forest cover within Kalimantan's WCMC lowland protected areas, based on analysis of MODIS satellite imagery. In 2001, only 9,510 km^2 (47%) of extant 'protected' lowland forest (dark green) had not been allocated to concessions or plantations. The remaining 'protected' lowland forest (light green) overlapped concessions or plantations (industrial land). At least 64% of Kalimantan's land area (light green and yellow) has been allocated to industrial logging and plantation uses. Dark gray areas are non-industrial land >500 m elevation (~50,000 km^2). Remnant fragments of non-industrial protected forest (dark green) occur predominately in less accessible montane regions (adjacent to areas >500 m shown in dark gray).

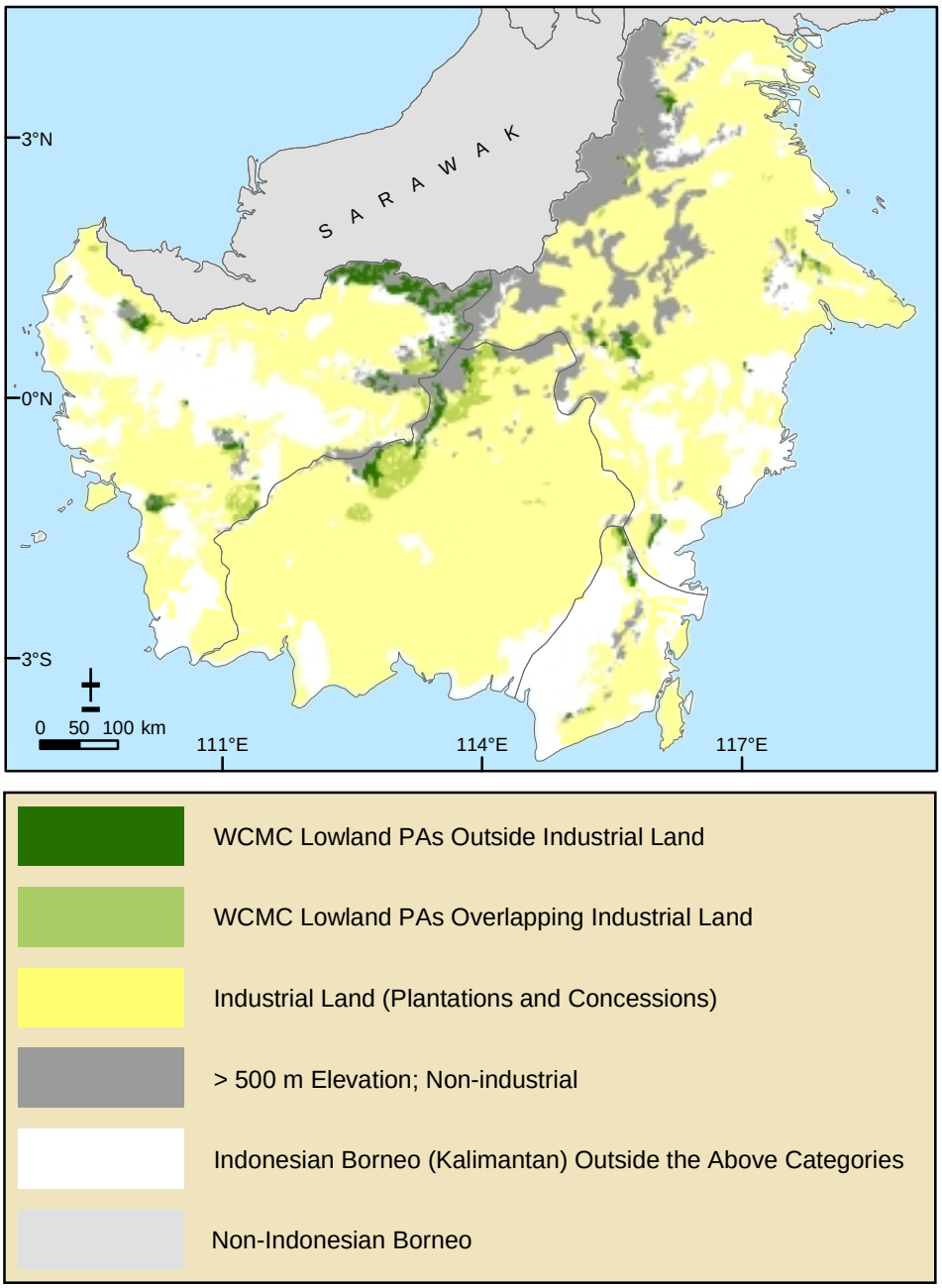


Table S1. Length and density of logging roads within WCMC Protected Areas.

WCMC Protected Area	Status	Park Area (km2)	Logging Roads (km)	Roads (km/km2)
Gunung Palung	National Park	1,016	20.8	0.020
Gunung Nuit	Game Reserve	1,409	33.0	0.023
Bentung Kerihun	National Park	7,877	0.9	0.000
Bukit Batutenobang	Protection Forest	4,656	191.1	0.041
Bukit Baka	National Park	1,864	119.4	0.064
Bukit Raya	National Park	3,298	534.1	0.162
Gunung Tunggal	Protection Forest	639	144.4	0.226
Bukit Permai	Protection Forest	1,827	351.5	0.192
Bukit Rongga	Protection Forest	1,378	263.2	0.191
Kelompok Hutan Sambas	Nature Reserve	396	95.7	0.242