Methods, Jurisdictional Risk Assessment (by Jessica L. Forrest for WWF-US)

Indicators were developed to assess potential risk to forested ecosystems and their management in Indonesia by district. These indicator sets represent: 1) primary forests, 2) peat lands, 3) protected areas, and 4) the forest estate (specifically, production forests and limited production forests). Depending on the ecosystem or managed area type, historical rates of deforestation, fire occurrence, and incompatible zoning of land uses (particularly by oil palm concessions) were selected as ways of evaluating risk

To produce indicators, datasets were downloaded from Global Forest Watch (www.globalforestwatch.org) and associated websites, augmented by a few external sources. To generate each indicator, the appropriate layers were overlain with Indonesian district boundaries in ArcGIS 10.3 (ESRI, Redlands, CA, USA) to generate zonal statistics by district. Statistics were further developed using MS Access and Excel (Microsoft Corporation, Seattle, WA, USA). All area calculations were completed in a Sinusoidal coordinate system with central meridian at 140 degrees, and with a Clarke 1866 Authalic Spheroid.

Datasets

The following datasets were used to generate indicators.

Name	Description	Source	Time Represented	Link
Jurisdictional Boundary	Administrative boundaries for Indonesia, at district level	GADM database	2014	http://www.gadm.org/
Tree Cover Canopy Density	Tree cover in the year 2000, defined as percent canopy closure for all vegetation taller than 5m in height	Hansen et al. 2013 (Hansen/UMD/ Google/USGS/NASA)	2000	http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html
Tree Cover Loss	Forest loss during the period 2000–2013, defined as a complete stand-replacement disturbance, or a change from a forest to non-forest state.	Hansen et al. 2013 (Hansen/UMD/ Google/USGS/NASA)	2000-2013	http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html
Primary Forest	Intact and degraded primary forests across Indonesia for the year 2000	Margono et al. 2014	2000	http://www.glad.umd.edu/dataset/primary-forest-cover-loss-indonesia-2000-2012

Primary Forest Degradation and Loss 2000-2012	Location of primary forest degradation and loss in Indonesia from 2000-2012	Margono et al. 2014	2000-2012	http://www.glad.umd.edu/dataset/primary-forest-cover-loss-indonesia-2000-2012
Pantropical National Level Carbon Stock Dataset (2000)	Above-ground biomass density (Mg C/ha)	Baccini et al. 2012	2000	http://whrc.org/publications-data/datasets/pantropical-national-level-carbon-stock/
Indonesia and Malaysia Peat Lands	Peat land in Indonesia, classified by depth	Ministry of Agriculture 2011	2000	http://gfw2-data.s3.amazonaws.com/country/idn/zip/idn_peat_lands.zip
Indonesia Active Archived Fires (NASA)	MODIS-derived hotspots and fire occurrence	NASA FIRMS	2010-2015	http://data.globalforestwatch.org/datasets/de1fe5832831464cbd64aaa8f2d54781_0 and https://firms.modaps.eosdis.nasa.gov/download/
Protected Areas	Legally protected areas	UNEP-WCMC 2016	2014	http://www.protectedplanet.net/
Government Concessions on Palm Oil	Boundaries of areas allocated by government to companies for oil palm plantation	Indonesia Ministry of Forestry	2010a	http://data.globalforestwatch.org/datasets/f82b539b9b2f495e853670ddc3f0ce68_3
Legal Classification for Indonesia	Protection status of land in Indonesia, including production forest, protection forest, conservation forest, non-forest, marine parks, and subcategories	Indonesia Ministry of Forestry 2010	2010b	http://data.globalforestwatch.org/datasets/04f797199b9441a28490410f91336b38_13
Indonesia Oil Palm Suitability Standard	Identifies potentially suitable areas for sustainable palm oil production, according to	WRI 2012; Gingold et al. 2012	2000-2010	http://gfw2-data.s3.amazonaws.com/country/idn/zip/idn_

Project POTICO	suitability.tif.zip

1. Primary Forests

The Primary Forest indicators report risk to primary forests in Indonesia, as a function of observed historic trends in forest cover loss from these areas, the density of fire occurrence, and percent of primary forests overlapped by oil palm concessions. Primary forest is defined as areas tree canopy cover density >=30% in the year 2000, > 5 ha in size, that had forest cover for at least 30 years prior to 2000 (Margono et al. 2014).

Total Percent Loss of Primary Forest Cover Loss (2009-2012, %) reports the percentage of original forest cover lost from primary forest from the beginning of 2009 to the end of 2012. To produce the indicator, primary forest cover representing the year 2000 (Margono et al. 2014) was intersected with tree cover loss through the ends of 2008 and 2012 (Hansen et al. 2013) to identify area of primary forest cover cleared between the beginning 2009 and the end of 2012.

We plotted the percent loss of primary forest cover against the original area of primary forest to see if very small districts were subject to bias towards high rates of forest loss. We found a slightly higher rate of loss among districts with smaller amounts of original forest cover but overall, districts with lower amounts of original forest cover showed a full range of percent loss of primary forest. To determine whether these mildly higher rates of loss on average were due to actual patterns or error, we examined patterns of tree cover loss in some districts with small original forest areas. We noted contiguous and realistic patterns of loss even from small original areas of primary forest cover. Accepting that some error is inevitable (from classification error and scale of the district boundary data), we excluded from the results (i.e., set to null) those districts where primary forest area at the beginning of the analysis period was < 5 ha. This process also removed districts from the results where the ecological value of primary forest is likely marginal. Five hectares is consistent with the filter applied by Margono et al. (2014) for defining “primary” forest.

We chose to display results in a map using the following numeric ranges: 0%, 0-5%, 5-10%, 10-25%, 25-50% and 50-100% . We selected these as ecologically relevant, actionable, and easy to remember. We applied the same categorization for display of the other 2009-2012 percent loss maps (peat forest and protected forest) to enable cross-comparability and interpretation.

Annual Average Rate of Primary Forest Cover Loss (2009-2012, %) presents an assessment of the percentage of original forest cover, on average, lost from primary forest on an annual basis from the beginning of 2009 to the end of 2012. Primary forest cover representing the year 2000 (Margono et al. 2014) was intersected with tree cover loss through the ends of 2008 and 2012 (Hansen et al. 2013) to identify area of primary forest cover cleared between the beginning 2009 and the end of 2012. Annual average rate of primary forest cover loss (%) (P) was subsequently derived using the function:

$$P = (1/ t_1-t_2) * ((A_2-A_1)/A_1) * 100$$

Where t = time=4 years, A=Area

(Also see: WRI 1995, Menon and Bawa 1997, Forrest et al. 2008).

Similarly to the percent area lost variable, a 5 ha minimum area threshold was used as criteria to present data for this indicator.

TREND IN ANNUAL AVERAGE RATE OF PRIMARY FOREST COVER LOSS (2000-2012) shows the direction of the slope in the ANNUAL AVERAGE RATE OF PRIMARY FOREST COVER LOSS (%), as an expression of whether the annual rate of forest cover loss has been increasing, decreasing, or remaining stable. To produce these figures, we began with Primary Forest Cover Loss and Degradation (2000-2012) for Indonesia. This dataset intersects primary forest cover (Margono et al. 2014) with tree cover loss data (Hansen et al. 2013) and accumulates loss and degradation over 2-5 year intervals (2000-2005, 2005-2010, and 2010-2012) to smooth out yearly inaccuracies in loss reports. We derived amounts and rates of forest cover loss only (omitting degradation) for the same 3 intervals, and then distributed this across annual intervals from 2000-2012. Slope was next calculated across the 12 years to report increasing, decreasing, or stable trends. Since slope alone does not adequately show curves in trends (such as normal, or exponential curves), we also calculated R^2 as a measure of tightness of fit of the points. An R^2 value close to 1 means a more defined unidirectional trend, whereas a lower R^2 value indicates a curve.

ANNUAL AVERAGE RATE OF PRIMARY FOREST COVER LOSS (%) (P) was subsequently derived using the function:

$$P = (1/ t_1-t_2) * ((A_2-A_1)/A_1) * 100$$

Where t = time, A=Area

(Also see: WRI 1995, Menon and Bawa 1997, Forrest et al. 2008).

For districts where primary forest in the year 2000 was < 5 ha, the result was set to null, consistent with the filter Margono et al. (2014). This was to address error that accumulates at finer scales than the input data layers, and because very small areas of primary forest may have marginal ecological value compared with larger blocks of habitat.

Guidance for Interpretation, Assumptions, and Caveats

ANNUAL AVERAGE RATE OF PRIMARY FOREST COVER LOSS (%) and **TREND IN THE ANNUAL AVERAGE RATE OF PRIMARY FOREST COVER LOSS** report recent historic loss and degradation in primary forest. Primary Forest represents only about 38% of all forest cover in Indonesia. Forest types not represented by this analysis include secondary and plantation forests. We note that primary forest is often already remote, or protected, and rates of loss from primary forest may be much lower than rates of loss over all forest types (Joppa and Pfaff 2009). Primary forest loss tends to proceed from areas that have already experienced degradation (Margono et al. 2014).

Both indicators are derived from tree cover loss data from areas of primary forest in the baseline year (>30% canopy closure, >5 ha in size, >30 years as forest prior to year 2000). Loss of tree cover may be from human or natural causes, and may occur as a result of mechanical harvesting, fire, disease, or storm damage. Partial pixel clearance and degradation are not represented so total forest loss may be underestimated. In addition, forest cover gain is not incorporated into these figures, so figures cannot be interpreted as net change in forest cover (GFW 2016).

Percent Loss and Annual average rate of primary forest cover loss (2000-2013, %) was calculated using tree cover loss data v. 1.2, which uses two slightly different approaches (2011-2014) and a new sensor (Landsat 8) beginning in 2013 (Hansen/UMD/Google/USGS/NASA 2016). We selected v. 1.2 tree cover loss data for this indicator since we wanted the analysis to extend up until the most recent time period possible at the time of the analysis. We also believed these inconsistencies would not be consequential when averaged over a 13-year time period. However, we used v. 1.0 of the tree cover loss data to calculate **Percent Loss**, **Annual average rate of primary forest cover loss (2009-2012, %)** and **Trend in Annual Average Rate of Primary Forest Cover Loss (2000-2012).** This is because results from shortened time intervals are likely to be more sensitive to the methodological changes in the underlying dataset applied during the most recent years. It is particularly important to use a consistently derived tree cover dataset when deriving trends, since this indicator compares rates of change among different time periods.

The formula we used to calculate the rate of forest may underestimate in the actual rate of loss. This is because baseline area (A_1) actually decreases as deforestation proceeds over time, effectively increasing the rate of change (Puyravaud 2003). The reliability of the results is dependent on the accuracy of the primary forest and tree cover loss input layers (Hansen et al. 2013, Margono et al. 2014). It is reasonable to assume from the above qualifications that we present a conservative estimate of the recent historical rate of primary forest cover loss.

The scale of the district and tree cover loss data may influence results, particularly in district border areas. In such cases, tree cover loss that appears to occur on one side of the border may actually have occurred on the opposite side. The use of the minimum area threshold (original forest area >= 5 ha) attempts to correct for some of this error when original forest area is low and the error from discrepancies in scale can be conflated.

Trend in Annual Average Rate of Primary Forest Cover Loss (2000-2012) shows the long term direction of the trend in forest cover loss, indicating whether forest cover loss rates are increasing, decreasing, or staying stable. It does not, however, do a good job of expressing a curve in these rates. As such, a rapidly decreasing trend from 2000-2005, followed by an increasing trend from 2005-2012 may appear as a stable trend, or simply a slight increase or decrease in rate of loss. R^2 is helpful to indicate the strength of the trend (a linear trend will have a high R^2 close to 1, while a curve will have a low R^2 value). It is necessary to view the rates of primary forest cover loss by annum or interval to thoroughly understand trends. Trends do not suggest whether natural or human processes are causing forest cover loss.

% Primary Forest Overlapped by Oil Palm Concession is an indicator of risk of conversion of primary forests to oil palm plantation. First, we produced a primary forest layer for the year 2013 by starting with data on primary forest for the year 2000 (Margono et al. 2014) and removing areas that experienced tree cover loss from 2000 to 2013 (Hansen et al. 2013). We used oil palm concession data from the Ministry of Forestry (2010a), which are government granted concessions. To avoid double-counting areas, we resolved overlapping concessions (either an error in data or representing actual boundary issues) by dissolving the oil palm concessions into one feature. We next calculated the area of primary forest in 2013, the area of oil palm concession, and the area of overlap by district to find the **% Primary Forest Overlapped by Oil Palm Concession**. If primary forest area in 2013 was 0, then the value of overlap was set to null because overlap would not have been possible.

Guidance for Interpretation, Assumptions, and Caveats

The oil palm concession data represents the boundaries of current and planned oil palm plantations in Indonesia (Ministry of Forestry 2010a). This data set is known to be incomplete and probably underestimates actual oil palm concession area, but it is currently the best available. Boundaries may not be accurate to scale, and thus subject to irregularities (GFW 2016).

Guidance for interpretation about the primary forest layer is provided in section 1A above.

While percent area of overlap is an initial indicator of risk to primary forest, the assessment of risk is improved with knowledge of total area of primary forest and ecological value. For example, a district with a large percent areas of primary forest under oil palm concession may actually have little primary forest overall, and thus it does not pose a high risk to primary forest *relative to other districts*. Conversely, a district with a low percent area overlap may have a large area of primary forest and thus, a large area of primary forest may be affected. Moreover, certain districts may have areas of primary forest that are particularly distinctive ecologically: they may include areas of high endemism, important bird areas, and tiger habitat (Dinerstein et al. 2007, AZE 2010, Birdlife International 2016).

Related to this, the analysis does not control for random distributions of protected areas and oil palm concessions: a district with little to no area under concession with at random have little to no chance of overlap with primary forest. The reasons for no concession in a district may range from lack of agricultural suitability, to lack of opportunity or access, to good, sustainable land use planning and zoning. For these reasons, we did not omit districts with little to no oil palm concession from reporting. Viewing this indicator alongside data on total areas occupied by primary forest and concession, and ecological importance can help clarify risk and priorities for conservation management. Multivariate analysis may help to further control for biases (Ferraro and Pattanayak 2006). Regardless of the limitations, districts with large percentages of primary forest overlapped by concession (particularly those with large areas of primary forest) are likely to be at risk of conversion.

AVERAGE FIRE DENSITY IN PRIMARY FORESTS (2010-2015) describes the frequency of fire observations per unit area of primary forest as an indicator of recent human or natural disturbances, and potential future impacts if trends continue. To produce this figure, we overlaid annual fire observation point data for the years 2010 - 2015 (NASA FIRMS, 2016) with primary forest in 2010 (Margono et al. 2014).

Fire observation frequency was averaged over the 6-year period. Average fire point density was next calculated by dividing the average fire observation frequency over the six-year period by the area of primary forest in 2010. Fire density was multiplied by 10,000 for ease of presentation and reporting. Fire observation density is presented to reduce bias caused by varying areas of primary forest by district (i.e., large areas of forest should at random have a greater occurrence of fire and we seek to control for this in the density estimate).

1G. Guidance for Interpretation, Assumptions, and Caveats

Fire observation data represents fires and warm spots observed by the MODIS sensor (Moderate Resolution Imaging Spectrometer), and represent the centroid of 1 km^2 pixels where fire was observed at the time of satellite overpasses occurring at 1-2 day temporal intervals. To be detected, active fires and hotspots need to be a certain size or intensity and active at the time of the overpass. Some fires may thus be missed depending on time of day, low intensity, cloud cover, heavy smoke, or canopy cover. Fires that burn longer than the interval of the MODIS overpass were counted as separate observations; observations are thus considered a function of both separate occurrences and fire duration. Large fires are counted as multiple, adjacent observations in a 1 km grid. Fires can result from both human and natural causes.

The primary forest data layer is subject to some of the same assumptions and caveats as those expressed in section 1a above.

It is important to note differences in the scale of the overlapping datasets used to produce the indicator. The fire data is available at 1 km^2 resolution, whereas primary forest data has a resolution of 30 m. The means that fire could have occurred anywhere within 707 m of the point (if on the diagonal of the pixel). So in actuality, this indicator represents fire point density in or in close proximity to primary forest. Fire near to primary forest can be an indicator of human population density or activity, and this can be a factor of risk to primary forest. Fire or human population density proximate to primary forests can correlate with edge effects like non-timber product use, tree felling, hunting, recreation that can cause disturbance, etc. (ref). Natural fires can be an important factor ecological process and factor in maintaining habitat heterogeneity or biodiversity. However, the occurrence of natural fires may increase in frequency or intensity in disturbed areas or areas affected by drought or long-term climate change (ref).

2. Peatlands

Total Percent Loss of Primary Peat Forest (2009-12, %). Peat lands are recognized as major carbon sinks, which when drained can release 2-3 times as much carbon to the atmosphere as forest (Davison and Jannsens 2006, Baccini et al. 2012), thus contributing to global warming. **Total Percent Loss of Primary Peat Forest (2009-12)** is an indicator of the clearing and draining process in recent years. To produce the indicator, primary forest cover representing the year 2000 (Margono et al. 2014) was intersected with tree cover loss through the ends of 2008 and 2012 (Hansen et al. 2013), resulting in layers of primary forest representing those two times. Next, primary forest cover was combined with the national peat lands map (Ministry of Agriculture 2011) and districts to find the area of peat forest by district at the beginning of 2009 and the end of 2012.

As with the other forest loss indicators, we reported results only for those districts with >=5 ha of peat forest in 2009, to eliminate error that might accumulate from input layers used to assess small areas.

As with the **Total Percent Loss from Primary Forest (2009-2012),** we chose to display results in a map using the following numeric ranges: 0%, 0-5%, 5-10%, 10-25%, 25-50% and 50-100% .

Annual Average Rate of Primary Peat Forest Loss (2009-12, %) shows the average amount of primary forest cover lost from peat swamp on an annual basis. To produce the indicator, primary forest cover representing the year 2000 (Margono et al. 2014) was intersected with tree cover loss through the ends of 2008 and 2012 (Hansen et al. 2013), resulting in layers of primary forest representing those two times. Next, primary forest cover was combined with the national peat lands map (Ministry of Agriculture 2011) and districts to find the area of peat forest by district at the beginning of 2009 and the end of 2012. ANNUAL AVERAGE RATE OF PRIMARY PEAT FOREST COVER LOSS (%) (P) was subsequently derived using the function:

$$P = (1/ t_1-t_2) * ((A_2-A_1)/A_1) * 100$$

Where t = time=4 years, A=Area

(Also see: WRI 1995, Menon and Bawa 1997, Forrest et al. 2008).

As with other forest loss indicators, we reported results only for those districts with >=5 ha of peat forest in 2009, to eliminate error that might accumulate from input layers used to assess small areas.

TREND IN ANNUAL % LOSS OF PRIMARY PEAT FOREST (2000-12) shows the long term direction of the trend in primary peat forest cover loss, indicating whether peat forest cover loss rates are increasing, decreasing, or remaining stable. In order to do this, Average annual rates of peat forest cover loss was first calculated over the intervals 2000-2005, 2005-2010, and 2010-2012, using Primary Forest Cover Loss and Degradation (2000-2012) and peat lands (Ministry of Forestry 2011) as an input. The primary forest dataset intersects primary forest cover (Margono et al. 2014) with tree cover loss data (v 1.0, Hansen et al. 2013) and accumulates loss over 2-5 year intervals to smooth out yearly inaccuracies in loss. We calculated slope across the 13-year period to report increasing, decreasing, or stable trends. Since slope alone does not adequately show curves in trends (such as normal, or exponential curves), we also calculated R^2 as a measure of tightness of fit of the points. An R^2 value close to 1 means a more defined unidirectional trend, whereas a lower R^2 value indicates a curve.

Guidance for Interpretation, Assumptions, and Caveats

TOTAL PERCENT LOSS, ANNUAL RATE, AND TRENDS IN PRIMARY PEAT FOREST LOSS indicators omit the dynamics of secondary and plantation forest on peat. However, we assume that primary peat forest is a measure of loss of the most intact carbon stocks. The peat layer was produced by the Ministry of Agriculture (2011). It has a scale of 1:250,000, which is appropriate for national level planning, but is less useful and the local level (Hamzah & Julianne 2016). The effect is that error may accumulate near edges; tree cover loss reported to occur on peat may occur nearby, or vice versa. Primary forest loss does not necessarily mean complete loss of soil carbon, which may proceed as a result of drying or draining (Harris and Sargent 2016). Much of the same guidance, assumptions and caveats described for the primary forest loss indicators (sections 1a – 1e) also apply to the primary peat forest loss indicators.

% PEAT SWAMP OVERLAPPED BY OIL PALM CONCESSION is an indicator of past and potential future risk of conversion of peat swamps to plantation, and associated risk of carbon emissions. Indeed, conversion of peat lands to plantation has been recognized as a major source of emissions in Indonesia**,** with each hectare of tropical peat drained for plantation development emitting an estimated average of 55 metric tons of CO_2 (Harris and Sargent 2016). We began with a peat lands layer (Ministry of Agriculture 2011) and treated all peat lands equally, regardless of depth. We also used oil palm concession data from the Ministry of Forestry (2010a), which represent government granted concessions. We resolved overlapping concessions (either an error in data or representing actual boundary issues) by dissolving the oil palm concessions into one feature. We next calculated the area of peat, the area of oil palm concession, and the area of overlap by district to find the **% Peat Overlapped by Oil Palm Concession**. For districts where peat land area is 0, we set the value to null because no overlap is possible.

Guidance for Interpretation, Assumptions, and Caveats

The oil palm concession data represents the boundaries of current and planned oil palm plantations in Indonesia (Ministry of Forestry 2010a). This data set is known to be incomplete and probably underestimates actual oil palm concession area, but it is currently the best available. Boundaries may not be accurate to scale, and thus subject to irregularities. Likewise, the peat lands layer is at a scale of 1:250,000, which has inaccuracies at the local scale.

These values mainly represent past and future risk of conversion of peat lands to oil palm plantations, and the coincident draining of peat swamps and carbon emissions. These figures do not correct for biases caused by the total areas of peat and oil palm concessions, nor the random distribution of oil palm and peat. For example, a district with a small area of peat land and a large area of oil palm concession could easily have 100% overlap, even if the area of oil palm concession is average. A district without any oil palm concessions will naturally have 0% overlap. The reasons for no oil palm concessions in a district may range from lack of agricultural suitability, lack of access or opportunity, to sustainable land use planning and zoning. Districts where peat land area and oil palm concession areas are both significant, but overlap is 0 or close to 0 may indicate good governance and low risk to peat swamps. Districts with large areas of peat and large areas of overlap represent high risk to this valuable ecosystem.

Average Fire Density in Peat Lands (2010-2015) describes the frequency of fire observations per unit area of peat land as an indicator of recent human or natural disturbances, and carbon emissions resulting from drying of the swamps. To produce this figure, we overlaid fire observation point data for the years 2010 - 2015 (NASA FIRMS, 2016) with peat lands (Ministry of Forestry 2011). Fire observation frequency was averaged over the 6-year period. Fire density per unit area of peat land was calculated to reduce bias from area of peat land (larger areas of peat would rationally be expected to have greater occurrence of fire). Average fire observation density was next calculated by dividing the average fire observation frequency during the six-year period by the area of peat land. Fire density was multiplied by 10,000 for ease of presentation and reporting.

Guidance for Interpretation, Assumptions, and Caveats

Fire observation data represent fires and warm spots observed by the MODIS sensor and represent the centroid of 1 km^2 pixels where fire was observed during overpasses occurring at temporal intervals of 1-2 days. Reported figures represent fires observed within or in close proximity (<707 m) of peat lands. Fire may have occurred from human or natural causes, and may be small or large. Areas of peat may have a variety of land cover types (primary forest, plantation, secondary forest, agriculture), and may or may not have already been converted and drained at the time of the fire. Fire density is likely underestimated due to detection deficiencies resulting from the temporal resolution, canopy cover, cloud cover, and heavy smoke. Nonetheless, we assume that fire observations in peat swamp likely correlate with actual fire occurrence in or near to this ecosystem. For other guidance for interpretation, assumptions and caveats about the fire data, please refer to Fire Density in Primary Forest (section 1d).

3. Protected Areas

Total Percent Loss of Primary Forest Cover Loss from Protected Areas (2009-2012, %) presents an assessment of observed loss and future risk to forest cover in protected areas. Forest cover loss may result from human or natural causes. Protected areas with high rates of tree cover loss may indicate illegal activity, since logging and land conversion are not allowed in conservation areas (Rosenbarger et al. 2013). We first produced primary forest cover layers for early 2009 and the end of 2012 by intersecting primary forest cover for the year 2000 (Margono et al. 2014) with tree cover loss through the ends of 2008 and 2012 (Hansen et al. 2013). We selected protected areas gazetted by 2009 from IUCN & UNEP-WCMC (2016) and converted the feature data to raster. We then combined the primary forest, protected area, and district data to produce estimates of protected primary forest by district in early 2009 and the end of 2012 and to calculate percent of baseline (year 2009) forest cover lost.

As with earlier forest loss variables, a 5 ha minimum 2009 forest area threshold was applied for inclusion in the results.

As with the **Total Percent Loss from Primary Forest (2009-2012)** and the **Total Percent Loss from Primary Peat Forest (2009-2012),** we chose to display results in a map using the following numeric ranges: 0%, 0-5%, 5-10%, 10-25%, 25-50% and 50-100% .

Annual Average Rate of Primary Forest Cover Loss from Protected Areas (2009-2012, %) presents the percent loss of primary forest cover by year from protected areas. We first produced primary forest cover layers for early 2009 and the end of 2012 by intersecting primary forest cover for the year 2000 (Margono et al. 2014) with tree cover loss through the ends of 2008 and 2012 (Hansen et al. 2013). We selected protected areas gazetted by 2009 from IUCN & UNEP-WCMC (2016) and converted the feature data to raster. We then combined the primary forest, protected area, and district data to produce estimates of protected primary forest by district in early 2009 and the end of 2012. The Annual average rate of cover Loss from Protected Areas (%) (P) was subsequently derived using the function

$$P = (1/ t_1-t_2) * ((A_2-A_1)/A_1) * 100$$

Where t = time=4, A=Area

(Also see: WRI 1995, Menon and Bawa 1997, Forrest et al. 2008). As with earlier forest loss variables, a 5 ha minimum 2009 forest area threshold was applied for inclusion in the results.

As with the **% Loss from Primary Forest (2009-2012)** and **% Loss from Primary Peat Forest (2009-2012),** we chose to display results in a map using the following numeric ranges: 0%, 0-5%, 5-10%, 10-25%, 25-50% and 50-100% .

Trend in Annual Average Rate of Forest Cover Loss from Protected Areas (2000-2012, %) shows the long term direction of the trend in forest cover loss in protected areas, indicating whether forest cover loss rates are increasing, decreasing, or staying stable. To produce these figures, we began with Primary Forest Cover Loss and Degradation (2000-2012) for Indonesia. This dataset intersects primary forest cover (Margono et al. 2014) with tree cover loss data (Hansen et al. 2013) and accumulates loss and degradation over 2-5 year intervals (2000-2005, 2005-2010, and 2010-2012) to smooth out yearly inaccuracies in loss reports. We intersected this data with areas protected by the end of the year 2000 (IUCN & UNEP-WCMC 2016) and with districts. We derived amounts and rates of forest cover loss only (omitting degradation) for the same 3 intervals, and then distributed these rates across annual intervals from 2000-2012. We next calculated slope from 2000-2012 to report increasing, decreasing, or stable trends. Since slope alone does not adequately show curves in trends (such as normal, or exponential curves), we also calculated R^2 as a measure of tightness of fit of the points. An R^2 value close to 1 means a more defined unidirectional trend, whereas a lower R^2 value indicates a curve.

We decided to display results according to whether they were negative, zero, or positive – indicating three very different trends. A negative trend indicates a decreasing rate of deforestation over the 2000-2012 time period (with more extremely negative values indicating a stronger trend, and negative values closer to 0 indicating a milder trend. A positive trend (i.e., with values > 0) indicates an increasing rate of deforestation – with higher values indicating a more extreme increase. A trend score of 0 indicates no change in the rate of deforestation.

Guidance for Interpretation, Assumptions, and Caveats

Protected area data in the World Database of Protected areas (WDPA) were provided by a number of sources: government sources whenever possible, supplemented by other sources as needed. Convention secretariats are sourced for internationally designated areas. All data in the WDPA has been verified either by the national authorities or by non-government expert partners. The protected area dataset is not necessarily a complete representation of all the conservation areas which have been designated in country; and its quality depends on the accessibility of accurate, comprehensive, up-to-date conservation areas information from data holders (IUCN & UNEP-WCMC 2016). The protected area dataset may also not consider protected areas that have experienced downgrading, downsizing, or degazettement over the course of the study (Mascia and Pailler 2011, WWF 2016).

Issues in the accuracy and scale of protected area data, district, primary forest, and tree cover loss datasets may mean that some primary forest loss reported to occur within protected areas may actually have occurred outside, and vice versa. In addition, primary forest loss from protected areas reported for certain districts may actually occur in the adjacent district. This type of error can accumulate near boundaries and small original forest areas. The minimum original forest area threshold (>= 5 ha) attempts to address this issues in districts where these errors may be conflated, but in other districts, it is something to be aware of.

We defined original forest cover as tree canopy density in the year 2000 >= 30%. Tree canopy density of 30% is a generous threshold of forest cover, though it is consistent with that applied by Margono et al. (2014) for part of the definition of primary forest. Others have also used 50% in tropical forests (Hansen et al. 2013, Forrest et al. 2015). Thus, this threshold may include primary, secondary, and plantation forests, as well as possibly less forested areas. Forest loss data is subject to some of the same assumptions described in section 1A. It can result from human or natural causes: high rates of loss may indicate illegal activity in conservation areas such as logging or conversation to large-or small-scale agriculture. Or, forest loss may result from natural disturbances such as hydrological process (which can be significant), wind and landslide disturbance, or natural fire (GFW 2016). Protected areas selected for this particular indicator were gazetted through 2014, so this indicator effectively represents tree cover loss experienced in current and future protected areas. The terrestrial area protected in Indonesia area increased by 5.3% from 2000-2014, so tree cover loss from protected areas may be overestimated in some districts. We also did not incorporate information on protected areas that experienced downsizing, downgrading, or degazettement, or PADDD (Mascia and Pailler 2011), so in these cases, tree cover loss may be overestimated. However, tree cover loss in protected areas may at times proceed or follow PADDD (Mascia and Pailler 2011). Despite these qualifications, districts that show higher rates of tree cover loss from protected areas likely indicate high observed and potential future risk to protected ecosystems.

% Protected Area overlapped by Oil Palm Concessions shows inconsistencies in land management and risk to biologically important ecosystems that protected areas are intended to protect. In Indonesia, it is illegal to establish plantations in conservation areas (Rosenbarger et al. 2013). Overlap of concessions with protected areas has been identified as a global phenomenon (including Indonesia) and attributed in part to lack of transparency in land use planning and communication between government departments (Landymore 2010, Forrest et al. 2011, Osti et al. 2011).

We calculated **% Protected Area overlapped by Oil Palm Concessions** by first selecting all protected areas gazetted through the year 2010 (IUCN & UNEP-WCMC 2016), to be consistent with the year of the oil palm concession data (Ministry of Forestry 2010a). We dissolved the protected areas data to one feature to eliminate areas with multiple designations and did the same for the oil palm concession data. We next intersected the protected area data with Indonesian districts, and calculated the area protected in each district. We did the same for oil palm concessions to find the area of oil palm concession in each district. Finally, we intersected protected areas by district with the dissolved oil palm concession data to find the area of protected overlapped by oil palm in each district. In particular, districts with overlapping protected and oil palm concession areas < 70 ha appeared to be an artifact of digitizing, and we thus removed these areas from reporting. Since districts without area protected or in oil palm concession could not have overlap, we set districts with < 5 ha in either land use to null. We selected 5 ha as a threshold to avoid including districts falsely noted as having these land uses due to inconsistent boundaries between the district and land use datasets.

Guidance for Interpretation, Assumptions and Caveats

The oil palm concession data represents the boundaries of current and planned oil palm plantations in Indonesia (Ministry of Forestry 2010a). This data set is known to be incomplete and probably underestimates actual oil palm concession area, but it is currently the best available. Boundaries may not be accurate to scale, and thus subject to irregularities.

Protected areas are subject to some of the same caveats. Protected area data are provided by a number of sources: government sources whenever possible, supplemented by other sources as needed. Convention secretariats are sourced for internationally designated areas. All data in the WDPA has been verified either by the national authorities or by non-government expert partners. The protected area dataset is not necessarily a complete representation of all the conservation areas which have been designated in country; and its quality depends on the accessibility of accurate, comprehensive, up-to-date conservation areas information from data holders (IUCN & UNEP-WCMC 2016). The protected area dataset may also not consider protected areas that have experienced downgrading, downsizing, or degazettement over the course of the study (Mascia and Pailler 2011, WWF 2016). Given some of the limitations of the dataset but also the way we prepared the analysis, we assume that percent area of overlap of protected areas by oil palm concessions is slightly underestimated, but nonetheless indicative of actual rates of overlap.

AVERAGE FIRE DENSITY IN PROTECTED AREAS (2010-2015) describes the frequency of fire observations per unit area of protected area as an indicator of recent human or natural disturbances in or close to these ecologically important areas. To produce this figure, we overlaid fire observation point data for the years 2010 - 2015 (NASA FIRMS, 2016) with protected area data for the years 2010-2015 (IUCN & UNEP-WCMC 2016). For example, fire occurrence in the year 2010 was overlaid with protected areas gazetted by the year 2010, fire occurrence in the beginning of the year 2011 was overlaid with protected areas gazette by the year 2011. The protected area dataset did not include protected areas gazetted after the year 2013, so we used protected areas gazette by 2014 for the years 2014 and 2015 fire overlays. From this, annual frequency of observed fire in protected areas was calculated for the years 2010, 2011, 2012, 2013 and 2014. Fire density per unit area of protected land was calculated for each year from 2010-2015. Next, the observed fire density values were averaged over the 6-year period to produce a single value for average [observed] fire density in protected areas. Fire density was multiplied by 10,000 for ease of presentation and reporting.

Guidance for Interpretation, Assumptions, and Caveats

Fire observation data represent fires and warm spots observed by the MODIS sensor (Moderate Resolution Imaging Spectrometer), and represent the centroid of 1 km^2 pixels where fire was observed during overpasses occurring at temporal intervals of 1-2 days. Due to the spatial resolution, reported observed fires may have occurred anywhere within <707 m of the point location. Fire may have occurred from human or natural causes, may be small or large, and have low to high disturbance effects. Fire density is likely underestimated due to detection deficiencies resulting from the temporal resolution as well as canopy cover, cloud cover, and heavy smoke. We assume that fire observations in protected areas likely correlate with actual fire occurrence within or in close proximity to protected areas. High fire density, even if outside but proximate to the boundary of a protected area, may indicate high human population density which can result in disturbance and edge effects to the protected ecosystem (ref).

4. Forest Estate

% FOREST ESTATE (PRODUCTION FOREST AND LIMITED PRODUCTION FOREST) ILLEGALLY OVERLAPPED BY OIL PALM CONCESSIONS is an indicator of inconsistencies in land use designations and risk to ecologically important forests. In Indonesia, it is illegal to have plantations in production and limited production forests (Rosenbarger et al. 2013). To produce this variable, we selected production and limited production forest areas from the Indonesia land use classification (Ministry of Forestry 2010b). We dissolved the layer to remove any areas of overlap and prevent double-counting, and intersected with district boundary data. We calculated the area of this land use type in each district. We next intersected with oil palm concession data (also dissolved to remove any overlap discrepancies), to find the area of overlap by district. We also calculated the area of oil palm concession by district. We used these figures to calculate the percent of production and limited production forests overlapped by oil palm concessions. We set the value to null if the area of production and limited production forests was 0, since no overlap was possible.

Guidance for Interpretation, Assumptions, and Caveats

The oil palm concession data represents the boundaries of current and planned oil palm plantations in Indonesia (Ministry of Forestry 2010a). This data set is known to be incomplete and probably underestimates actual oil palm concession area, but it is currently the best available. Boundaries may not be accurate to scale, and thus subject to irregularities. The land use zone data, from which the boundaries of production and limited production forest was drawn, also may have mild inaccuracies in boundaries. This data is dated to the year 2000, so some land use designations may have changed between then and the year of the oil palm concession data.

Significant area and percent area of overlap signal potential risk to managed forests (and the biological and ecosystem values they support), and lack of communication between government departments in the land use planning process. Initial assessment should be followed by verification to ensure that overlap is real and not an artifact of the data and years represented.

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