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Have Indo-Malaysian forests reached the end of the road?

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A B S T R A C T

The Indo-Malaysian region harbours some of the highest diversity globally, yet it is also has the highest rates of deforestation. Furthermore some countries have shown up-to a 10 times increase in the area deforested annually between 2001 and 2014. Large-scale forest clearance is preceded by the growth of road networks which provide a stark warning for the region's future as many of the roads established for clearance or infrastructure are illegal and unmapped. In some regions almost 100% of roads were previously unmapped on the global roads map, yet 99.9% of deforestation occurs within 2.5 km of these roads. In Borneo the majority of plantations are on an industrial-scale averaging over 10 km^2 in size, whereas most of the region typically has plantations under 1 km^2 integrated into a landscape mosaic, though the preliminary infrastructure for industrial plantations are being developed in parts of the region. Within the coming decade most of the region may lose almost all unprotected forests. As some countries have only 2% of their land-area protected this condemns many of the regions endemic species to extinction. Urgent measures are needed to protect a much larger proportion of remaining forest, as this offers the only means to protect many of the regions endemic species.

1. Introduction

The Indo-Malayan region represents a global biodiversity hotspot (Mittermeier et al., 2011), straddling the complex transition between Sundaland and Wallacea with multiple zoogeographic divides (Simpson, 1977; Rueda et al., 2013). However, this region has been highlighted not only for its' diversity, but the rapid rates of deforestation which in 2012 became the highest rates of loss globally (Achard et al., 2014; Stibig et al., 2014) and represents a major threat to the continued survival of many species (McCallum, 2015; Margono et al., 2014). Despite a moratorium on industrial deforestation in large parts of Indonesia in 2012 deforestation has continued to increase in recent years (de Vries et al., 2014) accounting for 61% of all Southeast Asian deforestation (Stibig et al., 2014), with 86.7–90% of deforestation classed as illegal of dubious legality (Lawson et al., 2014). Timber sourcing has also transitioned from predominantly selective logging in to conversion into plantations, which has been facilitated by the permit regulation system (Mukherjee and Sovacool, 2014; Indarto et al., 2015)).

Global demand for cheap palm-oil, with 84% going to Europe (30%) or Asia (54%) in 2015 (Atlas of Economic complexity, n.d.) and with 83% of this coming from Indonesia and Malaysia has fueled the conversion of forests to plantations (Media Atlas, n.d) Growing demand has been matched by exponential increases in oil-palm export, with export Indonesian and Papuan exports (Indexmundi Indonesia, n.d.) increasing by 437.4% between 1999 and 2016, and Malaysian exports increasing (Indexmundi Malaysia, n.d.) by 173%. The export of palm-oil is also dominated by illegally grown oil-palm (80–87%), as is pulp and paper production, with the two largest companies APP and APRIL (jointly responsible for 75% of the industry) showing "questionable legality" in 77% and 47.5% of conversions respectively (Lawson et al., 2014), these figures are similar to other studies for example Gellert (2015) found only 20% of plantations had been permitted by the Ministry of Forestry. Other studies have shown that at least a quarter of clearance falls outside government leased concessions (Gunarso et al., 2013) (though some of this may be legal small-holder clearance), and an estimated 90% of oil palm plantations in Kalimantan derive directly from formerly forested areas (Carlson et al., 2013a, 2013b). There is also no reason to expect these trends to change, as Indonesia plans to increase production to 42 million tons by 2020 (Jakarta Post, 2017), and further increases are expected after this point.

As global demand for these commodities continues to increase, this has been matched by the further loss of primary habitats and the mycelia like growth of roads across the region. Most global analysis overlook the development of these road networks, and their implications for the future of the regions biodiversity, and former studies (i.e. Ibisch et al., 2016) still class most of the region as "undisturbed", with extensive distances from road networks. This metric for "intactness" has also been utilized elsewhere (i.e. Newbold et al., 2016), thus such changes must be accurately accounted for to assay both direct loss and fragmentation, and to assess the vulnerability of regions in close proximity to roads to other forms of exploitation (i.e. hunting).

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Understanding where roads are, and what percentage are included in global datasets is important for a number of reasons. Firstly, road data indicates the areas most vulnerable to development in the near future, and though of course rivers can also provide access to forest for logging and other forms of utilization, analysis shows that roads account for almost all deforestation. Furthermore, like Ibisch et al. (2016) increasing numbers of global analysis are likely to make use of global datasets to assess threats to biodiversity and generate conservation priorities. For example Newbold et al. (2016) denote much of the Indo-Malaysian region to be relatively biotically intact, yet the data used to develop these assessments included only sparse biodiversity data from the region (Newbold et al., 2015) and used "proximity to the nearest road" to assess vegetation intactness. Given that these landscapes have been converted for agricultural production, they maintain low human populations, and thus the assumption that the global road dataset is complete and accurate for these regions provides a misleading assessment in many areas potentially at greatest threat. Though privately owned road maps may exist for parts of the region, and previous research has mapped roads in some areas (especially Borneo i.e. CIFOR, n.d.; Gaveau et al., 2014), these are likely to be both inconsistent in their reliability, and unavailable for large parts of the region; thus understanding the accuracy of global datasets is crucial to understanding and interpreting the reliability of the increasing numbers of analyses which make use of such datasets to inform conservation prioritization. Here we determine percentage of roads are unmapped in standardized global datasets and the percentage of deforestation which has taken place in close vicinity to these growing road networks, and discuss the future prognosis for the regions biodiversity.

2. Material and methods

The study region was chosen as based on remote sensing forests are visually and spectrographically similar enough for consistent mapping of roads across the region under study, further north (in other parts of Malaysia and Indonesia) it is well established that forests have been lost, and spectral differences make delineating roads consistently more challenging. Given the level of development in Northern Wallacea we focused on less urbanized parts of the region, and those where Oil Palm rather than pulp paper (i.e. Sumatra) have been stated to be the main tree crop (Gaveau et al., 2016), to attribute what proportion of deforestation can be accounted for by agricultural (primarily oil palm) production. This region was extended East to encompass all regions potentially at risk for oil palm production, hence extending as far as the Solomon islands as the extreme East of the Wallacean Archipelago. Thus this paper focuses on areas either at risk, or likely to become at risk of Oil Palm production in the near future, and where governance in addition to other pressures is likely to determine what proportion of the region remains protected, and what regions are likely to be converted (Fig. 1).

2.1. Mapping roads

OSM Roads (Open Street Map: a global map of roads) were downloaded (BBBike, n.d.), and merged to create a road map for the Indo-Malaysian region. Though OSM is known not to include all roads in some parts of the world, it is still used in global analysis (i.e. Ibisch et al., 2016), and therefore understanding spatial biases in road inventory completeness is key to the interpretation of such maps. Furthermore, many countries do not make national road maps widely available, and no national road maps for this region are openly available. This may stem from a fear of scrutiny on the rapid development of this infrastructure in formerly forested regions.

Across the Indo-Malay region 149 squares of 1866 km^2 each (covering a total of 277281 km^2, and spaced 55 km apart vertically and 70 km apart horizontally) were mapped out (Fig. 1). This method was used to give representative information on the area covered by roads without needing to map every road in each part of the region (which would have been time and resource intensive, and should yield the same result). Imagery data (using ESRI's image-server, n.d) and recent deforestation was used to manually map the presence of all roads located within each grid at very high resolutions (Fig. S1a–3b). These "unmapped roads" were appended to the OSM data, and the level of road inventory completeness ascertained. Primarily this approach was used because ESRI's imagery data has a much higher resolution than landsat imagery, (30 cm vs 30 m), thus this allowed the identification of roads which are likely to be invisible using landsat data. As ESRIs imagery data can be inconsistent in acquisition date this was cross-checked with the 30 m resolution deforestation data from Global Forest Watch to assay the deforestation of linear features.

Once all roads within the 149 grids were mapped out the total percentage of roads included in the OSM dataset was calculated. Following this the centroid of each grid was created and used to calculate the minimum distance to road using the original OSM dataset, and our mapped grid maps.

2.2. Deforestation

Area of forest and area deforested within each grid cell and at different proximities to formerly mapped and formerly unmapped roads were analysed. Deforestation data was downloaded from global forestwatch (30 M resolution), and forest data was provided by CRISP (Miettinen et al., 2016). CRISP data was not available for PNG, thus Crowther et al. (2015) tree density dataset was used to calculate the area of forest within countries and protected areas. These datasets were selected as they reliably delineate between different landcover, including tree-cover types. Hansen et al.'s (2013) dataset accounts for deforestation in a consistent and reliable way, but afforested areas are almost certainly converted into plantations of economically important trees. Though Hansens deforestation data may include some areas of plantation which have been cleared and replanted during the study period the extent of this is only likely to really be an issue in some of the older plantations in peripheral areas of Borneo, and given the challenges of accurately mapping forest relative to plantation make this challenging to separately analyse in a robust and comparable way without potentially high regional bias. Delineating the minimum density needed to qualify as "forest" is also challenging, especially with densely planted oil palm plantations a primary driver of forest loss, so the complementary utilization of all three datasets allow deforestation and forest coverage to be more accurately calculated. Roads (all roads, and OSM roads) were buffered at distances of 50, 100, 250, 500, 1000 and 2500 m. Deforestation occurring each year within each buffer distance was calculated.

2.3. Protected areas

The efficacy of protected areas was also calculated to determine the levels of deforestation within protected areas (Protected Planet, n.d) in states and countries across the region. Protected area maps were first dissolved, to prevent issues from overlapping protected area designations (Deguignet et al., 2017). Though the World Database of protected area maps may be incomplete these were cross-referenced with locally sourced maps from institutions in Indonesia and Malaysia, and found to largely be in agreement; thus the World Database of protected area maps (https://www.protectedplanet.net/) were used for consistency, and all protected areas included in the database used as the basis for assessment.

2.4. Mapping plantations

To explore the relationship between roads and oil-palm plantation establishment plantations established between 2001 and 2014 were mapped out by assaying if large contiguous deforested patches had been