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Hidden challenges to sustainable development along the Trans-Papuan Development Corridor

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Abstract

The island of New Guinea harbours one of the worlds' largest tracts of intact tropical forest, with 41% of its land area in the Province of Papua, Indonesia. Within Papua, the advent of a 4,000-km 'development corridor' reflects an Indonesia-wide agenda to promote land and resource exploitation while consolidating central authority over ethnically diverse regions. Papua contains vast forest and mineral resources. Local environmental and social considerations have been discounted in the headlong rush to establish the corridor and secure access to resources. Some conservation of peatland and forest is occurring near the epicentres of forest conversion. Customary land rights of Papua's diverse indigenous peoples remain an afterthought to resource exploitation and nationalistic priorities. New deforestation frontiers are emerging rapidly as the development corridor and other transport infrastructure expands. The integrity of the Lorentz World Heritage Site, the largest protected area in the Asia-Pacific, is being challenged on numerous fronts. A generic and centralised development agenda is driving virtually all of these changes. We recommend specific actions to reduce the environmental, economic and socio-political risks of escalating development pressures in Papua.

Keywords:

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1. Introduction

A trans-regional economic "development corridor" and associated Trans-Papuan Highway are emerging in Papua (West Papua and Papua provinces), far eastern Indonesia, to accelerate regional development. This corridor is one of a series being pursued nationally (CMEA, 2011), reflecting both national aspirations for increased resource and land exploitation (Negara, 2016; Alamgir *et al.,* In Press) and nationalistic goals to consolidate Indonesia's enthnically diverse population (Clements *et al.*, 2014; Laurance and Arrea, 2017; Alamgir *et al.,* 2017). Like many other large-scale infrastructure initiatives (Laurance *et al.*, 2015; Sloan *et al.*, 2016; Ascensão et al. 2018), the Papuan corridor is generating concerns over risks associated with environmental degradation and equitable development (Pattiselanno and Arobaya, 2015).

We identify three important but poorly observed challenges for sound development of the Papuan corridor: (*i*) partial peatland conservation among agro-industrial development, (*ii*) unresolved land claims threatening social equity and local economic development, and (*iii*) the emergence of new deforestation frontiers. Each challenge exemplifies discord between national and regional agendas associated with Papua's status as a resource frontier, complicated by Papua's unique social and environmental conditions. We conclude with proposals some of the key development and environmental challenges.

2. The Papuan Corridor and a Resource Frontier

Papua is a largely undeveloped, forested region that has long been managed as a resource-extraction frontier for Indonesia. It has been the focus of numerous forestry, agricultural, and mining mega-project proposals spanning tens of millions of hectares over recent decades (Carr, 1998; EIA, 2006; Rulistia, 2008). Driven largely by private commercial interests, most of these failed to materialise in the face of protest over environmental or indigenous issues and the global financial crisis of the late 2000s. The Papuan economic corridor differs critically in that it is driven by a national development agenda underlain by concerns over food, energy, and resource security. Once completed, the Papuan corridor will link growing epicentres of food/biofuel agriculture, mining, oil/gas extraction, forestry, and aquaculture via ~4000 km of upgraded and new highway crossing vast forest tracts (**Figure 1**). Supportive investments of $11.6 billion in secondary roads, ports, power generation, water sanitation, irrigation, and airports are already underway at various key nodes of economic activity (CMEA, 2011: 174). The Papuan corridor remains poorly scrutinised despite the significant regional implications of such developments, many of which have been critiqued at the local level (AwaMIFEE, 2013).

Papua's status as resource frontier poses distinct challenges to conservation and development along its corridor. Elsewhere in Indonesia, development corridors promote further logging, mining, and estate agriculture generally across previously exploited or settled landscapes, albeit with notable exceptions (Sloan, 2018, Alamgir *et al.* In Press). Consequently, local management issues there are typically foremost, e.g., remnant forest integrity, endangered fauna mobility. Contrarily, in Papua the concerted penetration of remote, intact forests stirs *foundational* issues determining future regional conservation and development dynamics. Shifts in these dynamics could set Papua on the same course as other Indonesian regions of 20-30 years ago, but now in a more globalised context steeped in a national development agenda. Indeed, recent environmental trends in Papua recall the earlier frontier-development phases of other regions, e.g., exponentially increasing deforestation rates (Chitra *et al.*, 2017), a high and growing fraction of forest concessions entailing forest conversion (Abood *et al.*, 2015; Austin *et al.*, 2017).

3. Forest Penetration, Reactive Management, and Missed Opportunities

Papua has long struggled to address conservation and development challenges arising from its mega-projects (Kirsky, 2017). In rare instances, such as the agricultural developments discussed later, a resemblance with earlier mega-projects (e.g., Aldhous, 2004) have provide at least some anticipation of the likely scope and scale of challenges. Yet with the ongoing penetration of Papua's remote regions, long subject to competing claims and civil conflict, relatively unexpected issues are also arising and outpacing sluggish, reactive planning.

The Lorentz World Heritage Site (WHS) is exemplary of such unexpected issues and reactive planning. Nearby forests were incorporated into the WHS just prior to corridor construction through and near this WHS in 2012. Such is best practice to prevent forest degradation arising from frontier road construction (Laurance *et al.,* 2012; Laurance *et al.,* 2009). Still, in Papua, even best practice may falter on weak foundations. Historically, local customary forest owners were indifferent towards the WHS designation and expansion, about which they were not consulted, and forest exploitation remained limited in large part due to its inaccessibility. Upon roading the vicinity, forest exploitation surged amongst customary owners and, importantly, amongst non-local loggers who negotiated access with customary owners and park guards (P. Mandibondibo pers. comm. July 2018). Ironically, rezoning the Lorentz WHS is once more being discussed, but now in relation to 'downgrading' its degraded areas.

Such contested, reactive forest management is poised to become more common in Papua as increased accessibility shifts the boundaries of land claims, extraction, and conservation. Papua greatly lags Indonesia in efforts to reconcile plans for development, conservation, land ownership and land use. Reconciled plans, known as 'One Map', are scheduled for national publication by 2019; yet less than one-third of Papua's maps were 'synched' as of mid-2018, compared to >80% in other regions (Jong, 2018). The recent legal recognition of customary forests[1] further complicates this difficult situation. Customary lands, a focus of Papua's indigenous separatist movement, are to be excised from the official forest estate, including protected areas and forest concessions, thus ceding managerial control to traditional owners (Siscawati *et al.,* 2017). However, of the 14 million hectares of customary forests under review nationally, only half have been 'registered' and virtually none of

[1] Constitutional Court Decision 35/2013.

these are in Papua (BRWA, 2018). There is therefore an immense reserve of Papuan land claims pending recognition within concessions and protected forests increasingly accessible via the corridor (Garnett *et al.*, 2018; Sulistyawan *et al.*, 2018) (**Figure 2**).

Customary owners are unlikely await formal recognition before intensifying the exploitation of their customary lands, including in protected areas. Neither are local governments likely to refrain from issuing new concessions, including within unrecognised customary forests. The upshot is that the Papuan Corridor is suddenly faced with uncertain scenarios that complicate both conservation and development. Three outcomes are simultaneously foreseeable:

- The rapid pace of agro-industrial development limits the potential to resolve competing claims, 'locking in' local grievances and unrest in Papua. Such is the case in south-eastern Papau, where traditional communities have reactively mapped only small niches of legal recognition within an increasingly established agro-industrial landscapes (Dewi, 2016; Sulistyawan *et al.*, 2018). Elsewhere, instances in which corporations improved highway segments in exchange for logging rights may preclude land claims entirely (Colombijn, 2002).
- Commercial loggers may operate increasingly through customary owners as the latter gain and consolidate access to their forests. Such an outcome has been observed in Kalimantan following a recent allocation of forests to communities there (Resosudarmo et al., In Review). In Papua, this outcome would be encouraged by the fact that most Papuan forest are precluded from new logging concessions by a national concession moratorium (Sloan *et al.*, 2014; Murdiyarso and Dewi, 2013). New forest exploitation may thus be spatially limited but probably locally intensive as a result. The untested regulation and legality of commercial logging on customary lands could aggravate strife and inequality amongst customary owners as well as between owners and the State.

- Investments and concession expansion along the corridor become mired by land claims, undermining the economic rational of the corridor. Such outcomes are common in neighbouring Papua New Guinea (Main and Fletcher, 2018). In Papua, stagnation is most likely to manifest along an emergent deforestation frontier in the east (discussed below) and the central isthmus, given their configurations of corridor construction and forests eligible for licensing.

4. Agro-Industrial Development and Overlooked Peatlands

Generic, centralized development approaches clash with both local priorities and ecological dynamics (**Box 1**). A case in point is the Merauke Integrated Food & Energy Estate (MIFEE) – a multi-million hectare agricultural and biofuel megaproject comprising the southern terminus of the Papuan corridor. The MIFEE and associated infrastructure expansion project was launched by Jakarta in 2010 (and re-energised in 2015) to increase national food and biofuel security (Yulisman, 2015; Indrawan *et al.*, 2016). However, the MIFEE and associated infrastructure occur amongst the world's most extensive and mis-represented peatlands.

Developments within the MIFEE region jeopardise peatlands despite ambitious peatland protections. The national peatland extent was recently revised (Ritung *et al.*, 2011; BAPPENAS *et al.*, 2013b; Wahyunto *et al.*, 2014) to refocus strong new peatland protections (Warren *et al.*, 2017: 3). As a result, the area of Papuan peatlands was reduced by 76% (4.4 Mha), in contrast to far lesser reductions elsewhere, largely due to delisting of substantial shallow peatlands (Warren *et al.*, 2017). The magnitude of this revision means that vast areas of probable peatlands in the MIFEE are subject to business-as-usual conversion along the corridor.

Across the MIFEE region, concessions for estate agriculture and pulp/timber plantations encompass at least 0.9 million ha of 'extra-official' peatlands (**Figure 4**) – known and probable peatlands recognized by Jakarta but omitted from its current peatland map. These 0.9 million ha are far greater than possibly anticipated, as MIFEE concessions now greatly exceeded the 1.6 Mha 'development clusters' originally designated for development (**Figure 4**) (AwaMIFEE, 2013). Concessions now extend contiguously along the Papuan corridor, from the westernmost MIFEE development cluster to beyond the northern and eastern limits of recent MIFEE deforestation (**Figure 4 stars**).

Peatlands revisions highlights a broader, inherently political trend to reframe actual and potential land use (Goldstein, 2016). Officially, MIFEE developments target 'grasslands' and 'idle', 'degraded' and 'underused' frontier lands. Such areas are not explicitly recognised by development plans, affording considerable latitude for their interpretation. Indeed, many agricultural concessions earmarked for development within the MIFEE are 60-80% forest, including peat forest (Brockhaus *et al.*, 2012). Recent MIFEE developments further evidence extensive deforestation (**Figure 4**). In this light, it is notable that Papua province had previously formulated a development plan recognising local uses of so-called 'idle' lands and restricting large-scale agro-developments such as the MIFEE (Suebu, 2009). Disagreement between this plan's 'alternative land uses' and Jakarta's generic forest licencing system ultimately promoted the latter over the former (Indrawan *et al.*, 2016), facilitating losses of peatlands and forests.

Papuan conservation-and-development planning authorities recently cited the national moratorium on new concessions (Murdiyarso and Dewi, 2013) as a 'failsafe' ensuring peatland integrity (T. Barano, pers. comm. 2018). This moratorium is, however, a partial and tenuous safeguard (Wijedasa *et al.*, 2018) largely peripheral to MIFEE developments. Crucially, the moratorium area is contingent on the presence of either (*i*) official peatlands or (*ii*) undisturbed 'primary' forests on mineral soils (Sloan *et al.*, 2012). Where neither is deemed present, as due to forest degradation and revised official designations, a local moratorium area may and, in all likelihood will, be annexed for development. Moratorium areas have regularly been annexed over years of iterative national revisions (Sloan, 2014), including within the MIFEE region.

5. Emerging Deforestation Frontiers

While new dynamics of forest exploitation and loss are unfolding, their location is becoming more apparent. New and old dynamics are converging along the corridor to define two potential frontiers of forest loss in eastern and central Papua. Both are poised to develop in the absence of countervailing activities.

The eastern frontier is defined by rare occurrence of forests that are (*i*) eligible for legal exploitation, (*ii*) proximate to intensifying exploitation and conversion, and (*iii*) situated along pending corridor segments (**Figure 5**). In its northeast, it is fringed by smallholder agricultural conversion that has expanded significantly due to population growth and the release of forest for conversion (Zeng *et al.*, 2018). In its south, the frontier is bound by incursions from the MIFEE, which have pushed along the Trans-Papuan Highway beyond their original northern limit. MIFEE concessions now butt against pre-existing logging concessions, which span much of the eastern frontier, defining a contiguous regional cluster of agro-industrial activity. Some ~250 km of new highway are planned across this juncture of agro-industrial and smallholder activity (**Figure 5**) and would open the logging concessions to new pressures. These concessions are presently intact, notwithstanding swidden cultivation; yet many are adjacent to agro-industrial conversion and/or occupied by smallholder communities. In Indonesia's older frontiers, such circumstances frequently led to the degradation, re-designation, and partial conversion of logging concessions (Sloan *et al.* 2018; Barr, 2001).

In central Papuan, the frontier is marked instead by mining concessions, which are also coincident with planned highway construction and prior forest loss (**Figure 6**). These concessions define a mining growth centre explicitly targeted by the corridor around one of the world's largest copper mines (**Figure 1**). Although many mining concessions remain in exploration stages, it is notable that that 19 exploration permits overlap 488 km^2 the Lorentz WHS, with many being deep within its interior (**Figure 6**). The location and extent of these permits clearly signal that future extraction within the WHS is a possibility – one that would be greatly facilitated by ~113 km of highway proposed across the Lorentz WHS and adjacent Enarotali Nature Reserve (**Figure 6**). Such mineral extraction within Indonesian protected areas is not without precedent. In 2012, Indonesia downsized its Batang Gadis national park by 385 km^2 to allow mining, and many others have been similarly downsized, downside or degazetted to accommodate oil palm, logging, and road building (**Table 1**).

6. Discussion

Papua is at a crossroads of conservation and development as activities consolidate around its corridor (Kusumaryati, 2017). The uncertainty surrounding forest rights and usage, the redefinition and loss of peatlands, and the emergence of deforestation frontiers all describe a situation where a national development agenda has displaced regional concerns and caught local administrations poorly prepared. In this light, we offer recommendations to strengthen conservation and development planning along the Papuan corridor.

6.1. Peatlands Revisited

The interplay between food-security policy and climate-change policy is exemplary of conservation and development trade-offs attributable to short-sighted planning. Indonesia committed to reduce its greenhouse gas emissions by 29-41% by 2030, of which 63% stem from forestry and land use (GOI, 2016b). It is contradictory therefore that the MIFEE was situated amongst extensive peatlands and forests, especially as the MIFEE has failed to produce rice – a tenet of its food-security agenda. Limited protections afforded by the moratorium also remain reversable where rice production is an objective (Murdiyarso *et al.*, 2011). Carbon emissions from burning peatland in the MIFEE during the 2015 El Niño recall the significant emissions from burning peatlands in the centrally-planned Mega-Rice project of Kalimantan (Aldhous, 2004; Page *et al.* 2002; Rieley and Page, 2008).

The extent of peatland and thus of peatland conservation should be immediately re-assessed across south-eastern Papua. The national peatland revision was simplistic and lacked field data (BAPPENAS *et al.*, 2013a), which where available suggested that Papuan peatlands were *more* extensive than originally estimated (Jaenicke *et al.*, 2008; BAPPENAS *et al.*, 2013a). In a perverse twist, recent national legislation has identified at least 158,000 ha in Papua (including the MIFEE) that may host fibre/timber and logging concessions translocated from elsewhere in Indonesia in the name of peatland protection (MoEF, 2017, Jong, 2018b).

The re-assessment of peatlands should be facilitated by the recently announced national initiative to remap Indonesian peatlands (WRI, 2018), which should commence in Papua. The re-assessment may fail to alter near-term Papuan dynamics in the likely event that Jakarta is slow to integrate the new peat map. District level officials may still revise concession applications according to interim peat data. Such revisions would be unlikely in the absence of a gubernatorial mandate – much like the logging ban in Aceh province (Linkie *et al.* 2014). Such a mandate would re-align Papua with its earlier low-carbon development plan.

6.2. Customary Claims as a Charge for Concessionaires

Agro-industrial developments in eastern Papua have been characterised as 'land grabs' (Goldstein, 2016; Ginting and Pye, 2011; Dewi, 2016). These were facilitated not simply by foreign investment and land enclosures but also by Jakarta's land-tenure regime that rationalised the use of 'idle lands'. As a result, Papuan customary communities have become overlooked in this realm despite strong legal recognitions otherwise[2]. The failure to resolve this contradiction means that there is significant potential that development will preclude customary land rights and associated economic opportunities for communities.

An enhanced, pre-emptive mechanism for addressing customary land claims along the Trans-Papuan Highway is required. Although mechanisms already exist to incorporate Papua's customary communities within the official tenurial regime, the process is exceptionally onerous for communities (e.g., Sulistyawan *et al.,* 2018). A dedicated technical / administrative team is required, often supplied by a NGO, for which reason Papua's customary land claims are drastically under-represented relative to Indonesian regions where NGOs are more active (BRWA, 2018).

A mechanism whereby concession proponents help identify and register local customary claims in collaboration with stakeholders would proactively address this issue. Doing so would also support the principles of 'free prior and informed consent' inherent to Papua's beleaguered

[2] e.g., Papua Special Autonomy Law 21/2001.

development plan. Such a mechanism also makes good business sense, as it would preclude many conflicts that beset Papuan concessions. It is however highly likely that proponents will baulk at the prospect of soliciting customary claims within their prospective concessions. Gubernatorial mandates and/or economic support would therefore again be required.

6.3. Mining in Protected Areas

Mining in the Lorentz WHS is arguably the most egregious of outcomes promoted by the Papuan corridor. Surprisingly, such an outcome would resonate with global trends: 38% of WHS are overlapped by mining, oil, and gas concessions (WWF, 2015). Although much of this overlap is probably due to imprecise boundaries for concessions and protected areas, this is not the case for the Lorentz WHS, which hosts numerous concessions adjacent to a major mine and a corridor intended to bolster mineral extraction. The fact that the Lorentz WHS is ranked 13th amongst >173,000 protected areas in terms of the uniqueness and vulnerability of its fauna (La Saout et al., 2013) underlines the regional and global significance of any biodiversity loss caused by mining. The very presence of these exploration permits undermines assurances that the WHS will remain intact – a goal already assailed on other fronts. In the interests of unambiguous conservation management, exploration permits within the Lorentz WHS should be nullified.

7. Conclusions

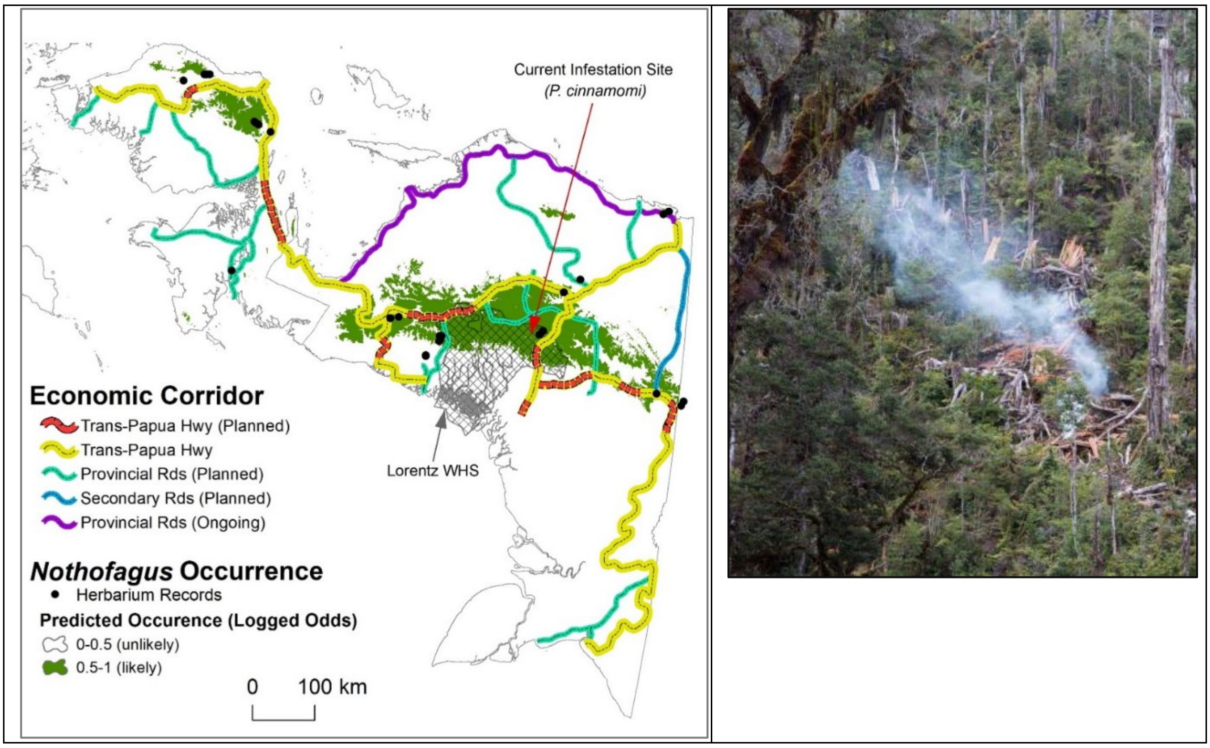
Anticipated Die-Back of Roadside Forests

As Indonesia's eastern extreme, Papua is located within the Australasian biogeographical realm and is thus uniquely host to *Nothofagus* forests (Read and Hope, 1996; Swenson *et al.*, 2001; Knapp *et al.*, 2005). This ancient genus is susceptible to the *Phytophthora cinnamomi* pathogen often spread by road-construction and traffic. Inexperience with this pathogen in Indonesia has allowed *P. cinnamomi* to establish itself along the Papuan corridor.

Safeguards against *P. cinnamomi* were not adopted during corridor construction. Best practice for road construction within *Nothofagus* forest entails regular disinfection of road-building machinery and soil aggregates to prevent *P. cinnamomi* spread (e.g., Esso Highlands Ltd., 2009). No such measures were taken in Papua as *P. cinnamomi* was not assessed as a risk, likely due to its unfamiliarity to those agencies undertaking environmental assessments.

Nothofagus infestation and dieback are now observable along the corridor within the Lorentz World Heritage Site (WHS) following the construction of a nearby highway segment in 2012 (**Figure 3** (GOI, 2016). Although officials have asserted that this dieback owes to climate change, with roads being an 'aggravating factor' (UNESCO, 2017), this remains unsubstantiated and discounts synergies between pathogens and climate. Due to this dieback, UNESCO is considering re-designating the Lorentz WHS as a World Heritage Site 'in danger'. Approximately half of the pending ~520 km of Trans-Papuan Highway construction would occur inside or immediately adjacent to *Nothofagus* forest **(Figure S1)**, according to bio-climatic modelling of its distribution (**Supplementary Materials**).

Figure 3 – The Probability of *Nothofagus* Forest Occurrence in Papua (left) and the Die-Back of *Nothofagus* forest due to infestation by the *P. cinnamomi* fungus, Lorenz World Heritage Site (right).



Note: Photo taken April 2016. Infestation site shown in the left panel.

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Figure 1 – The Papuan Economic Corridor and Major Zones of Economic Expansion.

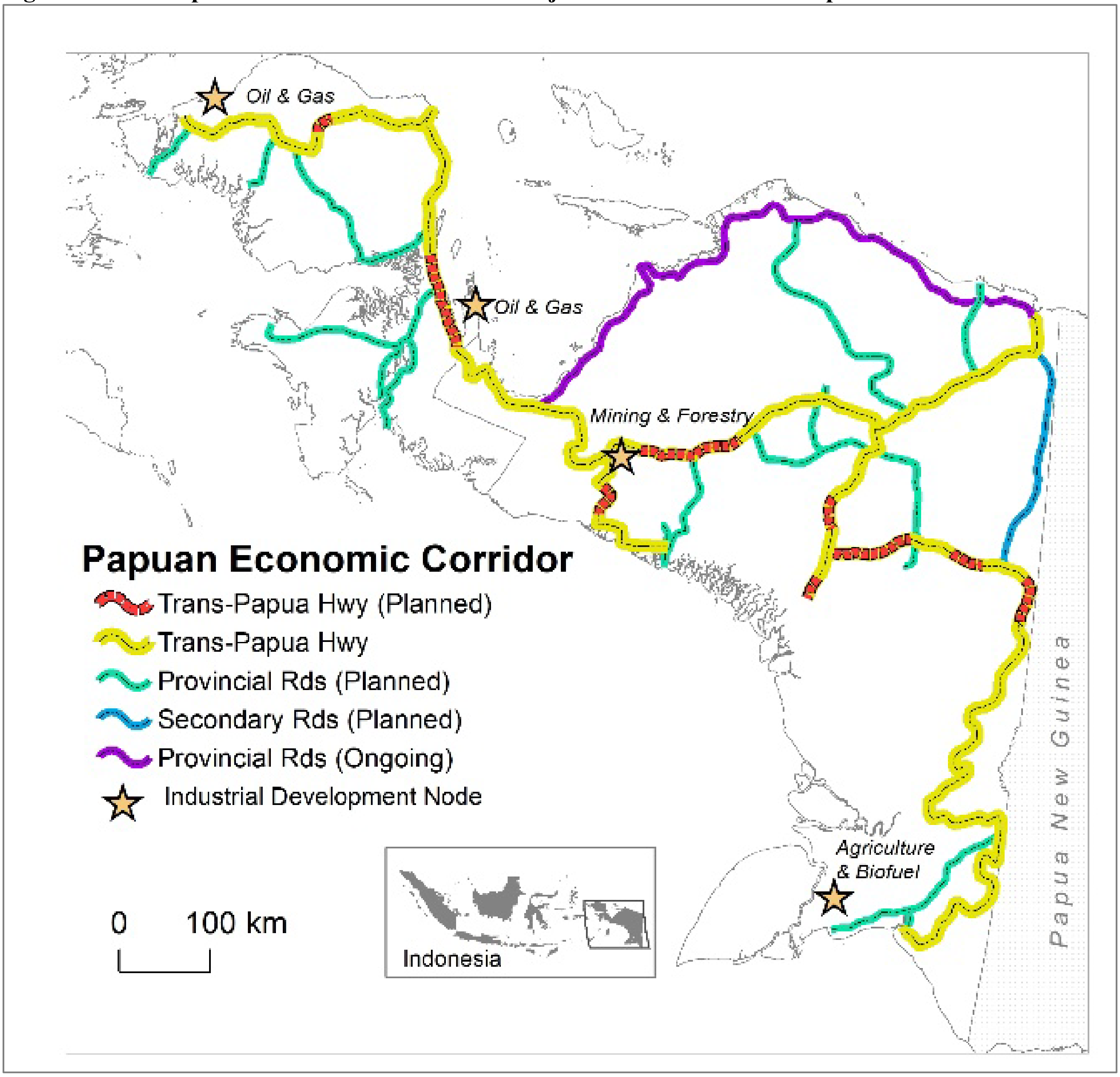
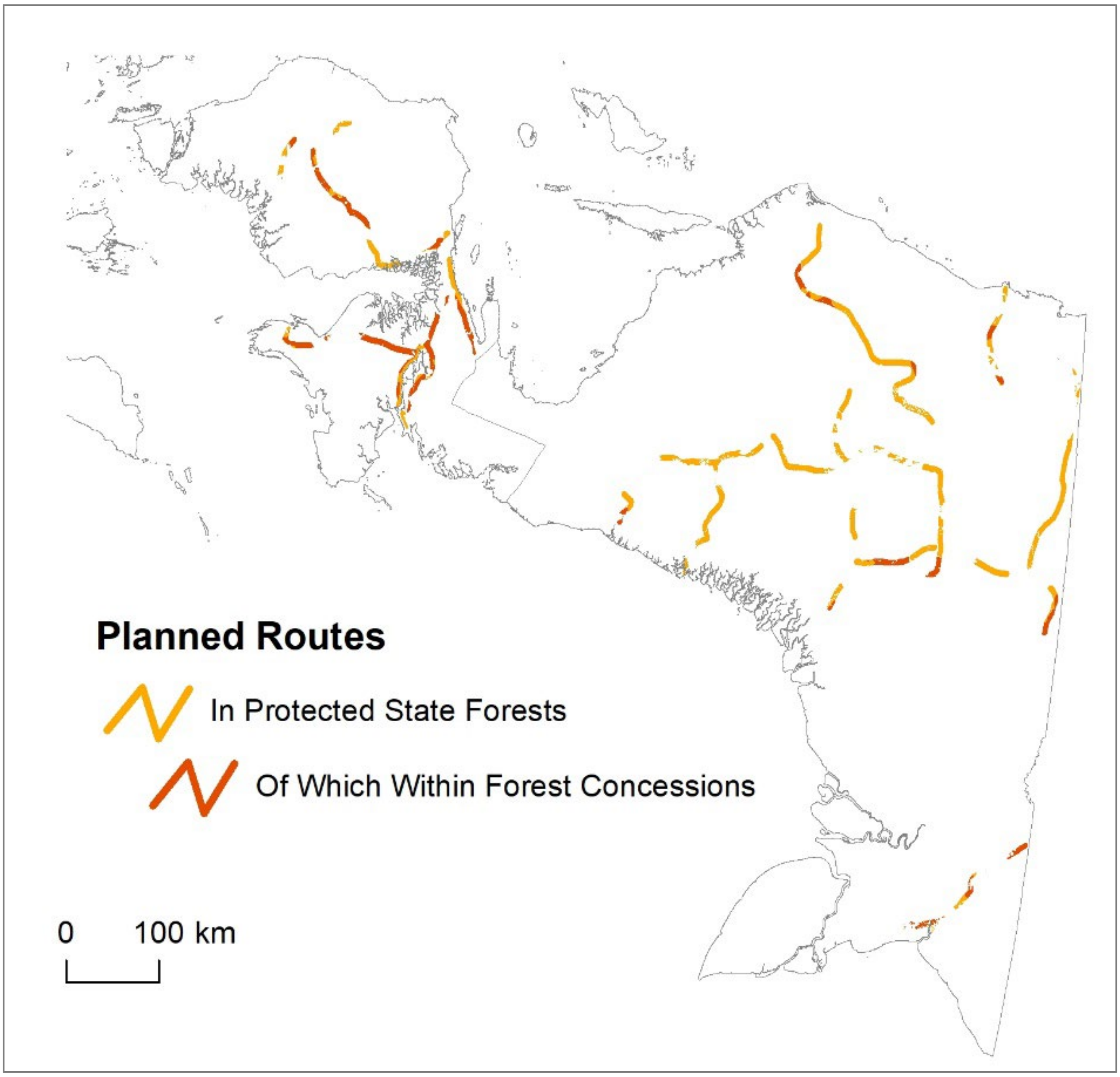
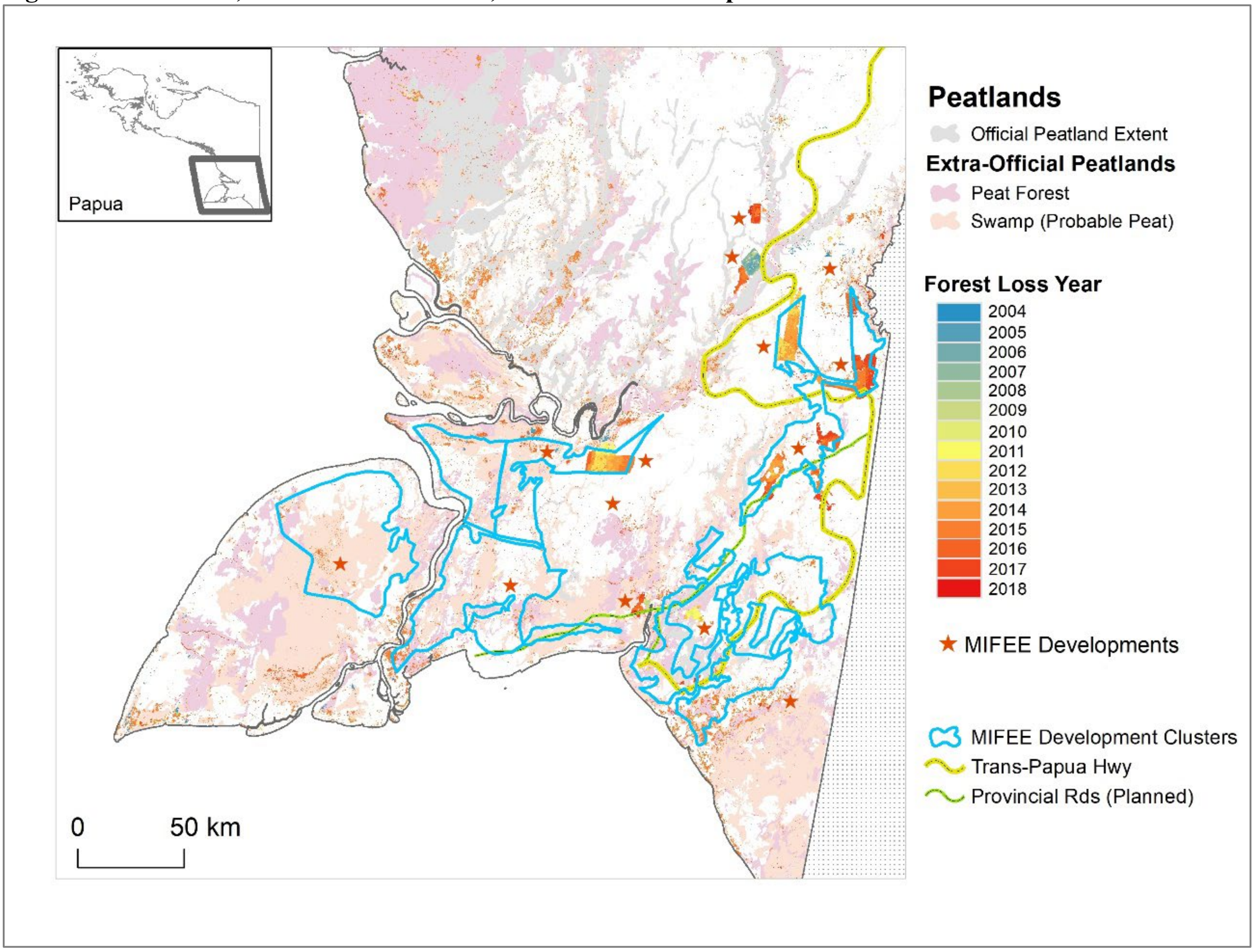


Figure 2 – Planned Routes of the Papuan Economic Corridor Highway and Associated Roadways Subject to Customary Land Claims within Protected State Forests and Forest Concessions.



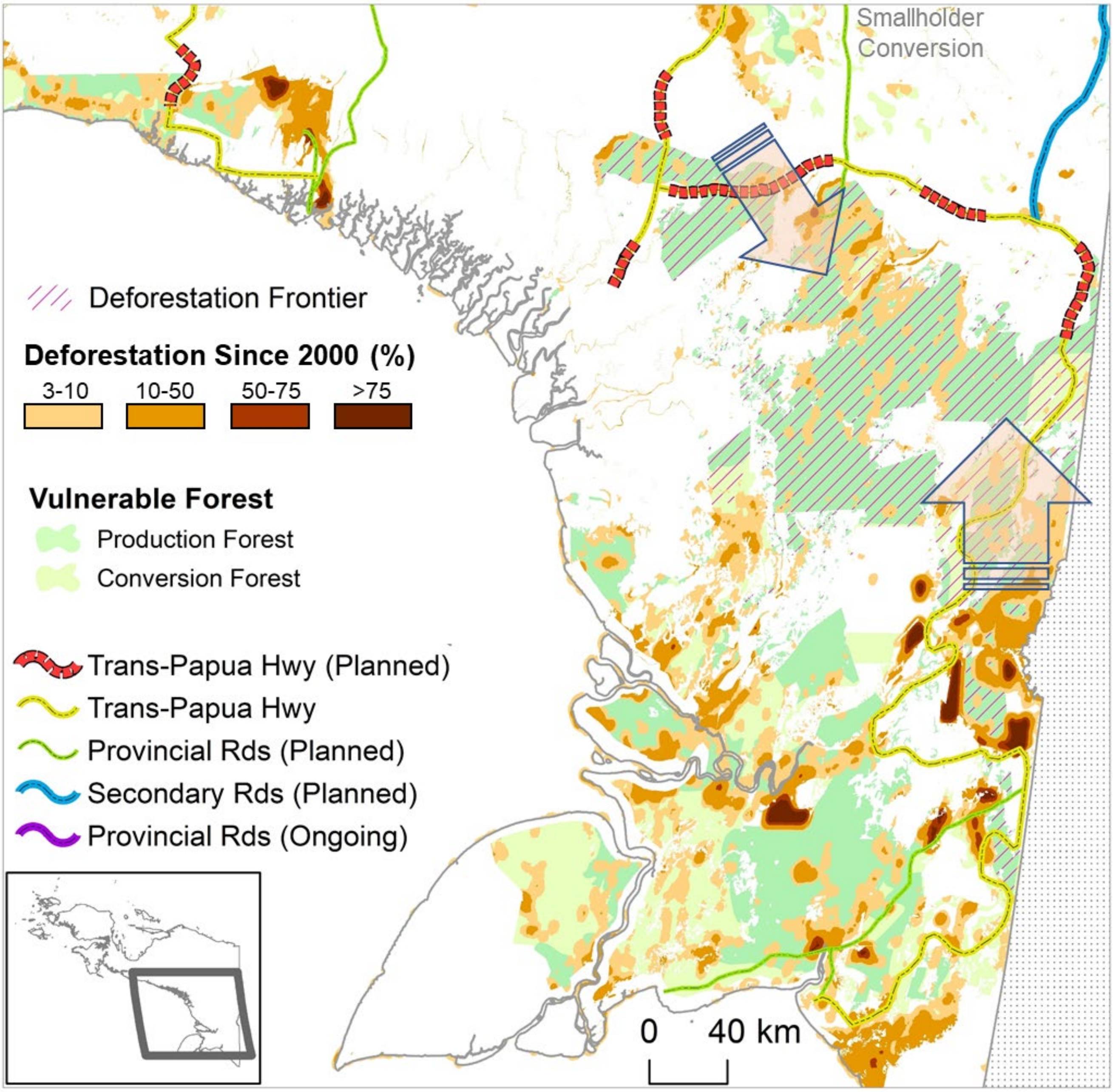
Notes: Planned routes are as per **Figure 1**, buffered by 3 km. The presence of actual forest cover is confirmed by the 2015 MODIS satellite image classification of Miettinen *et al.* (2016). Protected state forests is legally designated for conservation, protection, or permanent management. Forest concessions are with respect to oil palm, wood fibre, logging or mining (GFW, 2018c, b, d, a).

Figure 4 – Peatlands, Recent Deforestation, and MIFEE Development Clusters.



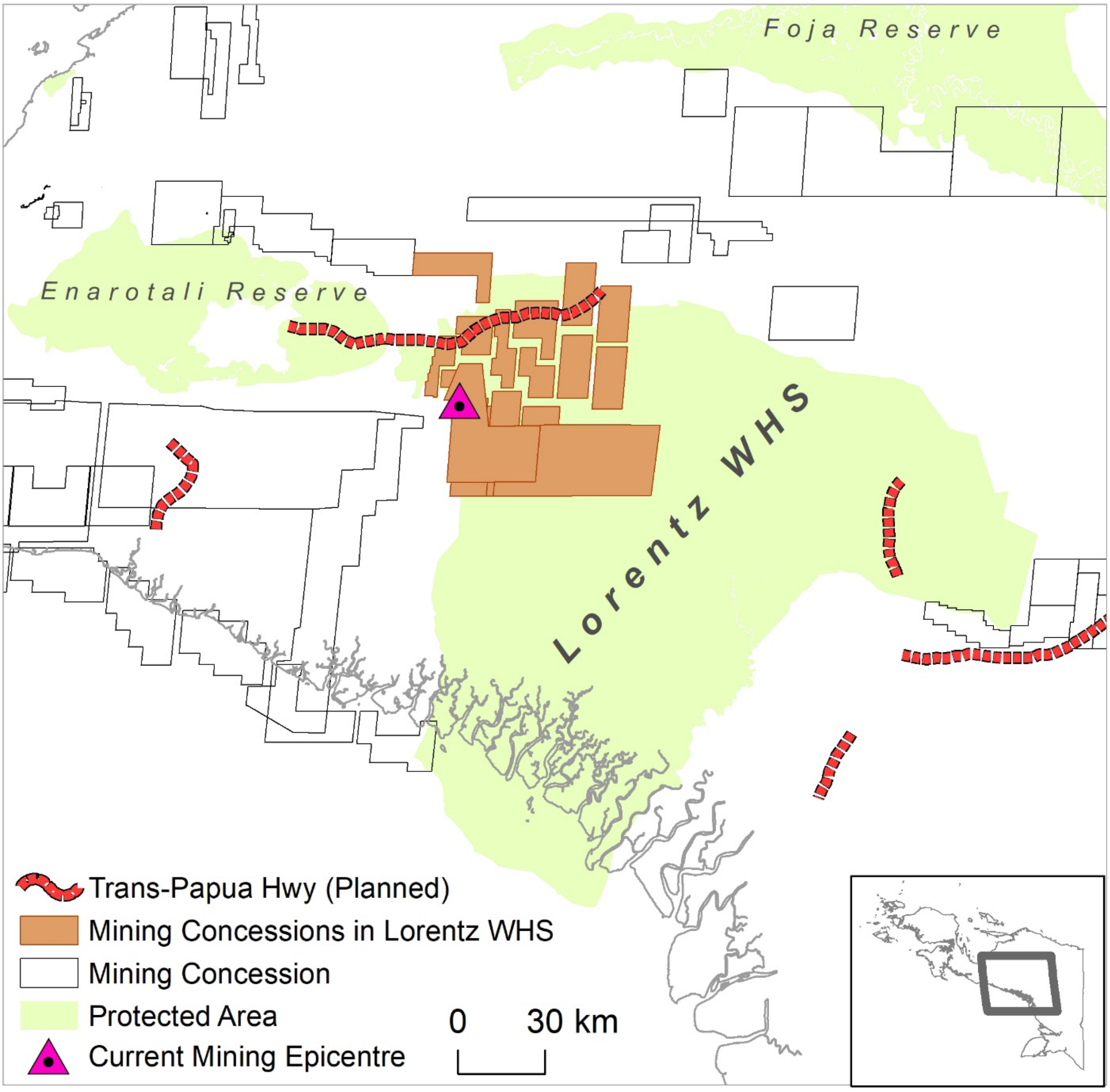
Notes: Extra-official peat forest and probable peatlands: Defined respectively by the peatswamp forests and swamplands classes mapped by the Ministry of Environment and Forestry (MoEF, 2015). They extensively overlap the independent, pre-revision extent of peatland previously used widely in Indonesia (Wahyunto and Subagjo, 2006), but were omitted from the revised official peatland extent (Ritung *et al.*, 2011; Wahyunto *et al.*, 2014). Forest losses by year: Compiled from automated deforestation alerts produced from weekly 30-m Landsat and daily 250-m MODIS satellite data (Hansen *et al.*, 2016; Reymondin *et al.*, Submitted).

Figure 5 – Potential Deforestation Frontier: Agro-Industrial Expansion in Eastern Papua.



Notes: Vulnerable forest is exclusive of the moratorium area. Production forest is designated for logging but is often degraded and converted illegally. Conversion forest is designated for agriculture. Deforestation spans 2000-2017 according to (a) updated (v. 1.5) annual 30-m Landsat classifications of Hansen *et al.* (2013) and automated deforestation alerts produced from (b) weekly 30-m Landsat and (c) daily 250-m MODIS satellite data (Hansen *et al.*, 2016; Reymondin *et al.*, Submitted). Data were re-sampled to 100-m for processing. Deforestation rate refers to the percentage area deforested since 2000 within a 3-km radius of a pixel.

Figure 6 – Potential Deforestation Frontier: Mineral Extraction Around the Lorentz WHS.



Notes: Current mining epicentre is the Grassberg gold and copper mine.

Table 1 – Examples of Protected Areas Downgrading, Downsizing or Degazettement (PADDD) in Indonesia.

Protected Area	Event	Cause	Event Year	Area Affected (km^2)
Batang Gadis National Park	Downsized	Mining	2012	385
Berbak Game Reserve	Downsized	Industrial Agriculture	1965	Unreported
Berbak Wildlife Sanctuary	Downsized	Unreported	1990	731
Halimun-Salak National Park	Downsized	Land Claim	1992	2.5
Kerinci-Seblat National Park	Downsized	Forestry	1990	Unreported
Kerinci-Seblat National Park	Downsized	Infrastructure	1992	2531
Kerinci-Seblat National Park	Downsized	Industrial Agriculture	1985	Unreported
Kerinci-Seblat National Park	Downgraded	Infrastructure	2011	Unreported
Kutai National Park	Downsized	Forestry	1971	1060
Kutai National Park	Downsized	Industrialisation	1990	14
Muara Kendawangan Nature Reserve	Downsized	Unreported	1993	260
Pleihari Tanah Laut Reserve	Degazetted	Industrial Agriculture	1992	60
Tanjung Putting National Park	Downsized	Industrial Agriculture	2013	358

Source: PADDD database of WWF and CI (2018).

Supplementary Text

Nothofagus Forest Distribution Modelling

The probable distribution of *Nothofagus* forest was modelled across the island of New Guinea (Papua and Papua New Guinea) on the basis of the topographical and climatic attributes of observed *Nothofagus* occurrences. As detailed by Read and Hope (1996), who provide the authoritative description of the *Nothofagus* genus for New Guinea, *Nothofagus* occurrence in New Guinea is strongly influenced by elevation and, to a lesser degree, temperature. Accordingly, our modelled distribution of Nothofagus corresponds well with the simpler New Guinean *Nothofagus* distribution estimated by Read and Hope (1996) on the basis of herbarium records and a minimum elevational threshold (>2000 masl).

Nothofagus occurrence was predicted across New Guinea using a cross-validated MaxEnt modelling approach (Phillips *et al.*, 2006). Modelling was trained using 469 *Nothofagus* occurrences across New Guinea derived from geo-located herbarium records compiled by the Australian Living Atlas (https://biocache.ala.org.au/occurrences). Given these occurrence, 10 models of *Nothofagus* distribution were defined, in turn allowing for 10 cross-validations, thus providing an estimate of the variability about the mean prediction. Each of the 10 models was based on a separate 90% random subset of the herbarium records and subsequently cross-validated on the corresponding 10% 'hold-out' subset. The mean prediction amongst these 10 models is displayed as **Figure 3**.

Nothofagus occurrence modelling incorporated four predictors: (i) elevation above sea level (Danielson and Gesch, 2011) and (ii) three principle components summarising all 19 WorldClim climatic variables for temperature and precipitation during 1970-2000 (**Table S1**) (Fick and Hijmansq, 2017). The three principal components in question accounted for 99.1% of climatic variability across New Guinea. The WorldClim climatic variables were resampled from their native ~800-m resolution to the ~250-m resolution of the elevation data before deriving their principal components. Predictions of *Nothofagus* distribution were considered insensitive to any imprecision of the geographic coordinates of the herbarium records since such imprecision would unlikely affect local topographical or climatic values meaningfully.

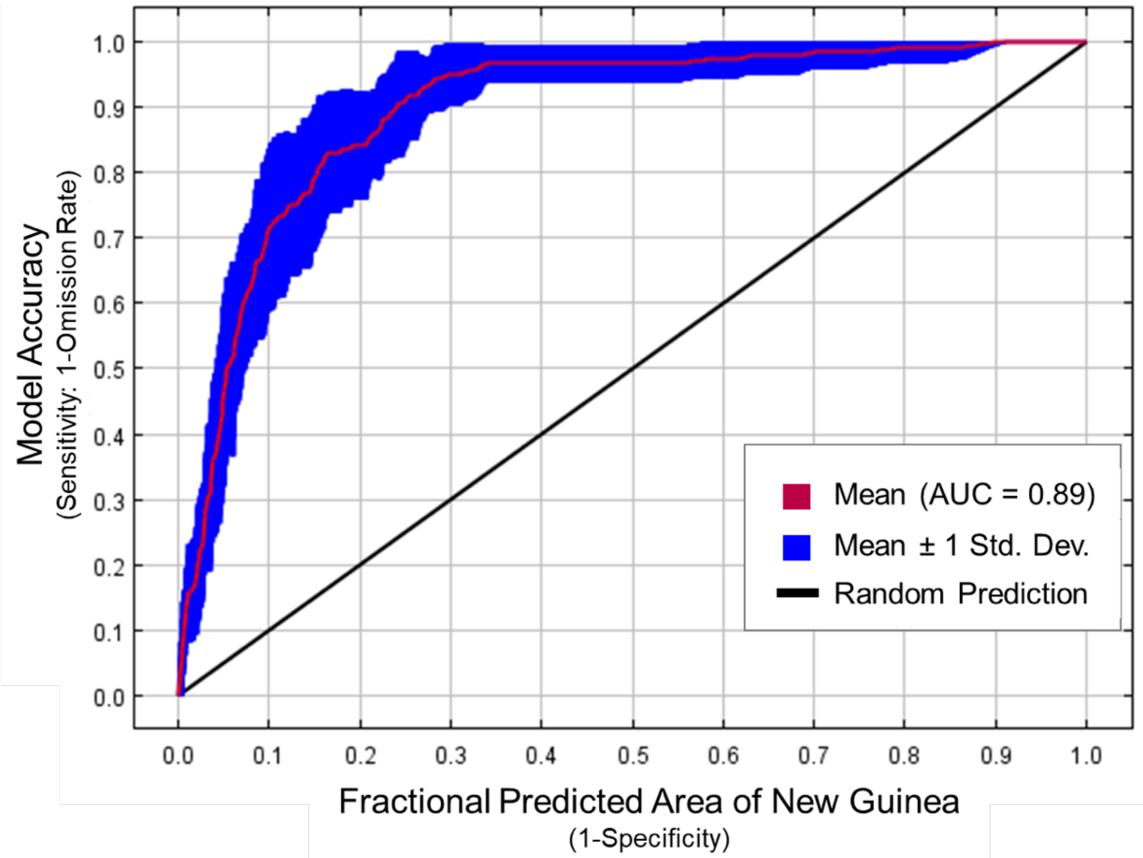
The mean predicted distribution of *Nothofagus* forest is considered highly accurate at a regional scale. A common measure of the utility of a species distribution model – the area under its receiver operating characteristic (ROC) curve – was 0.896 in the case of the mean predicted *Nothofagus* distribution, where 1.0 indicates a perfectly accurate predicted distribution and 0.0 indicates an entirely erroneous (i.e., random) predicted distribution. This statistic may be interpreted as the expected rate of accurate predictions of *Nothofagus* occurrence (Fielding and Bell, 1997). As illustrated in **Figure S1**, the value of this statistic rises rapidly relative to a random prediction (diagonal line) as a progressively greater proportion of New Guinea's area is considered (x-axis). Here, the proportional area of New Guinea serves as a proxy for model commission error rate. This commonly-used proxy is necessary due to the fact that the model considers occurrence data only, not absence data (Phillips *et al.*, 2006). At ~30% of New Guinea's area, the mean rate of true positive prediction reaches its asymptote of ~95% (**Figure S1**), reflecting the confined montane distribution of the *Nothofagus* genus.

Table S1 – Climatic Variables Reduced to Principal Components.

1	Annual Mean Temperature
2	Mean Diurnal Range
3	Isothermality
4	Temperature Seasonality
5	Maximum Temperature of Warmest Month
6	Minimum Temperature of Coldest Month
7	Temperature Annual Range
8	Mean Temperature of Wettest Quarter
9	Mean Temperature of Driest Quarter
10	Mean Temperature of Warmest Quarter
11	Mean Temperature of Coldest Quarter
12	Annual Precipitation
13	Precipitation of Wettest Month
14	Precipitation of Driest Month
15	Precipitation Seasonality
16	Precipitation of Wettest Quarter
17	Precipitation of Driest Quarter
18	Precipitation of Warmest Quarter
19	Precipitation of Coldest Quarter

Note: Climatic variables are as per WorldClim v2 global climatic dataset (Fick and Hijmansq, 2017).

Figure S1 – Accuracy of Mean Predicted Distribution of *Nothofagus* Forest in New Guinea as Described by the Receiver Operating Characteristic (ROC) Curve.



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