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Biological Conservation 241 (2020) 108369

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Does biodiversity benefit when the logging stops? An analysis of conservation risks and opportunities in active versus inactive logging concessions in Borneo

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ABSTRACT

The island of Borneo is a biodiversity hotspot of global importance that continues to suffer from one of the highest deforestation rates in the tropics. Selective logging concessions overlay a third of the remaining natural forests in the Indonesian part of Borneo, but many of these concessions have become inactive in recent years. Whereas the cessation of logging could be beneficial to biodiversity, the absence of a logging company's presence in the forest could also leave the concession open to deforestation by other actors. Using remote sensing analyses, we evaluate 1) whether inactive concessions are more likely to suffer from deforestation than active ones, 2) the possible reasons why concessions become inactive, and 3) which inactive concessions hold the most potential for biodiversity conservation, if protected from deforestation. Our analysis shows that, counterintuitively, inactive concessions overall suffer a higher rate of forest loss than active ones. We find that small concession size and high elevation are correlated with inactive status. We identified several inactive concessions that, if maintained as natural forest, could significantly contribute to biodiversity conservation, as exemplified by their importance to two umbrella species: Bornean orangutan (Critically Endangered) and Sunda clouded leopard (Vulnerable). Because timber operations in other tropical regions are likely to experience similar cycles of activity and inactivity, the fate of inactive timber concessions and the opportunities they create for conservation deserve much greater attention from conservation scientists and practitioners.

1. Introduction

The loss of biodiversity through species extinction is one of the foremost challenges facing humanity in this century (Ceballos et al., 2015; IPBES, 2019). The island of Borneo is a global biodiversity hotspot: it harbours many endemic species and has lost over 30% of its forest cover between 1973 and 2010 (Gaveau et al., 2014). Deforestation on Borneo is continuing at one of the highest rates in the world (Myers et al., 2000; Betts et al., 2017; Turubanova et al., 2018). Populations of many charismatic, forest-dependent species, such as the Bornean orangutan (*Pongo pygmaeus*) and the Sunda clouded leopard (*Neofelis diardi borneensis*), as well as thousands of other lesser-known plant and animal species are diminishing rapidly because of commodity-driven deforestation and associated hunting pressure (Curtis et al., 2018).

In Kalimantan, the Indonesian part of Borneo, natural forests allocated by the government to selective timber extraction (hereafter selective logging concessions) account for 17% of all land, and, in 2010, accounted for 30% of remaining forested land (Gaveau et al., 2013; Abood et al., 2015). Selective logging in tropical forests causes a partial loss of biodiversity, but that loss is much smaller than what occurs after a forest is converted to other types of land use, such as oil palm plantations (Gibson et al., 2011; Chaudhary et al., 2016). Furthermore, the loss of biodiversity due to selective logging can be reduced by

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https://doi.org/10.1016/j.biocon.2019.108369
Received 21 May 2019; Received in revised form 2 November 2019; Accepted 29 November 2019

modifications to logging practices, such as lower logging intensities, Reduced Impact Logging, and longer timber harvest rotation times (Bicknell et al., 2014; Burivalova et al., 2014; Griscom et al., 2018). Selectively logged forests, therefore, can act as important habitats, buffers, and corridors for biodiversity, as well as a potential 'placeholders' for future conservation areas, if properly managed (Edwards et al., 2014).

Tropical timber industries typically go through a 'boom and bust' cycle, meaning that timber extraction and export increase until forests are practically depleted (Shearman et al., 2012), at which point harvest declines dramatically or ceases altogether. Further, global trends in timber trade can also contribute to such cycles. Over-exploited forests are often seen as no longer commercially valuable, and subsequently may be converted to more profitable land uses, such as agricultural crops and plantations. In the last three decades, the forestry sector in Indonesia has undergone a dramatic change as the total area of forestry concessions declined from > 60 million ha in 1993, to < 19.3 million ha in 2017 (Romero et al., 2015). Some concessions have been converted to *Acacia* plantations for pulp and paper production, which have increased from < 1 million ha in 1993 to > 10 million ha in 2017, and some to oil palm (*Elaeis guineensis*) plantations, which grew in area from 2.1 million ha in 1995 to 11.1 million ha in 2015 (Gaveau et al., 2013; Austin et al., 2017). This trend of conversion is likely due to the lower profitability of selective logging when compared to monoculture plantations. This difference in profitability is particularly pronounced after natural forests have been selectively logged for the second or third time, and timber yields have declined substantially (Fisher et al., 2011; Chaudhary et al., 2016).

Possibly as a part of this larger trend, many logging concessions in Indonesian Borneo appear to have become inactive over the past few years, i.e. companies are not carrying out timber extraction on these concessions. One might suppose that the cessation of logging in an inactive concession would benefit biodiversity, but this inactivity could, in fact, pose a threat if the absence of logging activity and associated personnel provides an opportunity for others to move in and deforest the site or convert it to agricultural use. In such situations, biodiversity would benefit only if the government, a local community, a conservation NGO, or another institution stepped in and was willing to invest in managing inactive concessions in a conservation-compatible fashion, as for example protected areas, community managed forests, or sustainably managed forestry concessions under biodiversity-friendly management practices. As such, the fate of inactive concessions is worth investigating both as a threat and an opportunity for biodiversity conservation.

Other countries may be undergoing a similar shift within their timber industries (Shearman et al., 2012), with selective logging becoming substantially less profitable than alternative uses of the land such as food and biofuel production. However, the global demand for timber is also increasing, and timber production practices may be shifting from selective logging towards more intensively managed plantations. The potential time lag between forest concession abandonment and allocation to a new land use may offer an important opportunity for conservation across the world's forests. However, research is needed to identify such cases and to assess what is likely to happen with and without conservation intervention.

In this paper, we investigate what happens to concessions that have been inactive for a year or more in East and North Kalimantan, Indonesia, and whether, through judicious selection of sites, conservationists can advance biodiversity conservation by protecting inactive concessions. We chose two umbrella species as a proxy for the conservation value of inactive concessions in this region: Bornean orangutan and Sunda clouded leopard. These two are arguably the best-studied species in Kalimantan in terms of their habitat requirements and distribution (Husson et al., 2009; Spehar et al., 2015; Ancrenaz et al., 2016; Hearn et al., 2018; Macdonald et al., 2018a, 2018b; Voigt et al., 2018). The IUCN Red List currently classifies the Bornean orangutan as Critically Endangered and the Sunda clouded leopard as Vulnerable. The Bornean orangutan's population has declined by 25% over the last decade (Santika et al., 2017; Voigt et al., 2018) and, although it can sometimes use heavily modified habitats, such as oil palm plantations, it cannot survive and reproduce only in homogeneous oil palm plantations (Ancrenaz et al., 2015). The population of Sunda clouded leopards was predicted to fall by 62.5% from 2010 to 2020, based on projected rates of forest loss (Macdonald et al., 2018b). The Sunda clouded leopards very rarely occur in modified habitats (Macdonald et al., 2018a).

These two species, collectively, are therefore likely to be a good proxy for a large number of other species, as their ranges do not overlap extensively (the Bornean orangutan is predominately found in the lowlands, while the clouded leopard is largely a highland species), and they are dependent on natural forests. Mammals, especially top predators like the Sunda clouded leopard, have been shown to be useful umbrella species (Sergio et al., 2006; Branton and Richardson, 2011), even though this concept is not uniformly accepted (Roberge and Angelstam, 2004; Roth and Weber, 2008).

We explore the following questions: (1) Are inactive concessions more prone to deforestation and conversion than active concessions? (2) What factors likely contribute to a concession becoming inactive? (3) Which of the currently inactive concessions in our study region would be most valuable for biodiversity conservation if protected from further disturbance?

2. Methods

2.1. Overview

Our approach consists of identifying which concessions are active and which are not, quantifying the amount and sources of forest loss over a 16-year period (2000–2016) in active versus inactive concessions, quantifying their conservation value in terms of estimated densities of Bornean orangutans and Sunda clouded leopards, and quantifying the future threat to these concessions in terms of forest loss risk. We performed all GIS processing in ArcMap and all statistical analyses in R.

2.2. Identifying inactive concessions

One of the authors (BW) contacted individual concession managers in East and North Kalimantan to establish whether each concession was currently (2018) active or not, typically in person or by phone, using his extensive network of contacts in the Indonesian forestry industry. We classified a given concession as active if we were told that timber was being extracted or planned to be extracted in 2018 and if the logging licence for that concession was active. We were not able to establish how long logging had been taking place within the active concessions, nor when logging had last occurred within the inactive concessions, which are important limitations to consider when interpreting our results.

To verify our classification, we compared our findings with the status of a subset of concessions as reported by the Ministry of Forestry (MoF) in 2016. Our definition of inactive concessions is slightly different from the MoF definition, which classifies concessions as inactive if concessionaires report no logging activity for three consecutive years. Additionally, whereas the MoF classification is applied to entire companies, we also obtained information on individual units (separate polygons), in cases where a company leases several such units. In this article, we refer to these individual polygons as concessions. In the majority of cases, our classification as active vs. inactive concessions corresponded to the MoF classification. There were several exceptions, and these can be divided into cases where: *i*) we found the concession to be active, but MoF data show the concession was not active for 3 years 2014–2016 ($n = 2$); it is possible that these concessions re-started logging after 2016; *ii*) we found the concession to be active but according to MoF it had not been active at all between 2006 and 2016 ($n = 1$); *iii*) we found some, but not all units of a concession to be inactive, but the concession was classified overall as active in MoF records ($n = 14$ units); *iv*) we found the concession to be inactive but the MoF showed it was active, however, not in the last 2 years of MoF records (2015,2016, $n = 6$). In the small number of cases where our status assessment differed from that of the MoF, we chose to go with our assessment because it was completed more recently.

2.3. Sources and extent of forest loss to date

To quantify the amount of deforestation that occurred in each concession from 2000 to 2016, we used forest loss data produced by the Global Forest Change initiative using Landsat satellite imagery, wherein a pixel is classified as having lost forest cover if canopy cover is reduced by 50% (Hansen et al., 2013). The resolution of this data set is ~30 m per pixel, which is sufficient to detect selective logging roads and larger gaps created by logging, as well as forest clearing for agriculture, but it likely misses the smaller logging gaps caused by selective logging. Therefore our estimates of total forest loss are probably underestimated (Burivalova et al., 2015). We did not account for forest gain in order to prevent counting mature monoculture plantations (Acacia and oil palm) as forest (Tropek et al., 2014). Whereas there were likely very few mature plantations in the year 2000, some may have matured enough over 16 years to be mis-classified as forest gain.

In order to establish whether the sources of forest loss differ between active and inactive concessions, we used the same forest loss data set (Hansen et al., 2013) to classify the deforestation patterns in each concession as follows (Fig. 1): (1) selective logging – very small, isolated forest perforations, along a road-like pattern. Forest loss due to selective logging could occur in an inactive concession either before or after the concession became inactive, the latter possibly due to illegal logging. (2) Smallholder agriculture – small, irregularly shaped patches, larger than those from selective logging. An inactive concession could become vulnerable to forest loss from smallholder agriculture if the timber company no longer asserts its presence after logging ceases. (3) Industrial agriculture – regularly shaped, large deforested patches, typically containing oil palm or acacia monocultures. Such deforestation often results from inconsistencies in mapping concession boundaries across different government departments (e.g. forestry, mining, and agriculture). An inactive concession could experience forest loss from industrial agriculture if the timber company is no longer present or interested in disputing the overlapping land allocations (Gaveau et al., 2013). Alternatively, a concession could become inactive *because* of too much pressure from industrial, commodity-driven deforestation, or too much conflict with smallholders that frustrates the logging company. Also, parts of logging concessions that are already heavily degraded due to selective logging, fires, or smallholder encroachment could be reassigned by the appropriate ministries to different industries. (4) None/natural – no or very little forest clearing, with perforations isolated from roads and randomly distributed. In our analysis we assume that an active concession that is being legally logged under the full control of the logging company should only have the first and last type of forest loss (1 and 4).

We visually examined and assigned each concession as having or not having each type of deforestation (i.e. one concession could have multiple sources of deforestation). Next, we performed a series of chi-squared tests to establish whether each type of deforestation pattern was over- or under-represented in active and inactive concessions, and whether deforestation types occurred independently of each other. We did not quantify the amount of forest loss by source; we were only able to calculate the overall forest loss.

2.4. Factors associated with inactivity

In order to understand whether there are biophysical or socio-economic characteristic differences between active and inactive concessions, we tested six candidate variables (Table 1) in separate logistic regression models, with the probability of a concession being inactive as a response variable. We envisage three main situations arising: 1) A company purchases a permit, starts and continues to do logging. This is an active concession. 2) A company purchases a permit, does logging for a few years, and then stops (e.g. it runs out of money, logging becomes not profitable, etc.). This is an inactive concession, but it could become active again in the future. 3) A company purchases a permit, but never begins logging (e.g. it doesn't have the capital to start a logging operation, it realizes the timber stock is too low, etc.). This is an inactive concession, which could also become active in the future. Active, as well as inactive concessions could be re-assigned by the government to another use (e.g. plantation, or protected forest).

2.5. Deforestation threat

We determine conservation priority both by the sites' conservation assets and the level of threat they face. In order to evaluate the level of future threat for each concession (beyond potential threats associated with concession inactivity), we used the Borneo forest loss risk map (Cushman et al., 2017), which estimates the likelihood that a given pixel will be deforested in the near future (2020). The model takes into account deforestation drivers at multiple scales and is the most recent and comprehensive forest-loss risk map for Borneo (Cushman et al., 2017). It does not, however, take into account the inactivity of forestry concessions as a potential driver of forest loss. For each concession, we calculated the mean and sum of pixel values from this layer, and then ranked concessions from most to least at risk of deforestation.

2.6. Conservation value of inactive concessions

Bornean orangutan – we used the spatial distribution of estimated Bornean orangutan densities for the year 2015 as determined by Voigt et al. (2018). This model is based on 36,555 field observations of orangutan nests along 1743 ground and aerial transects. The model explains the spatial distribution of the nests by several environmental and anthropogenic variables, most notably climate, forest cover by forest type, human population density, and study year (Voigt et al., 2018). For each concession, we calculated the mean and sum of pixel values for the estimated orangutan density. The sum therefore represents the estimate of total number of Bornean orangutan individuals within each concession, and the mean represents the mean Bornean orangutan density across the concession. We then ranked the inactive concessions according to the mean and sum of Bornean orangutan densities, from highest to lowest.

Sunda clouded leopard – we used the spatial distribution of estimated population size and population connectivity of Sunda clouded leopard for year 2010 as determined by Macdonald et al. (2018b). This model is based on habitat suitability estimates generated by expert elicitation and land cover classification. A panel of 13 experts, consisting of researchers directly involved in field research on Sunda clouded leopards, was involved in the parameterization of the model (details in Macdonald et al., 2018b). A further study based on data from 1544 camera traps stations (138,516 trap nights) identified habitat variables that best explain Sunda clouded leopard detections, and these were in agreement with the expert elicitation (Macdonald et al., 2018a). In the expert elicitation-based model, Sunda clouded leopards are estimated to disperse on average 125 km, and the total effective population size is estimated to be ~2500 individuals for Borneo. Using connectivity modelling (resistant kernel and least-cost path approaches) two data layers were produced that we used in our analysis: *i*) expected density of dispersing individuals and *ii*) likely location and strength of corridors

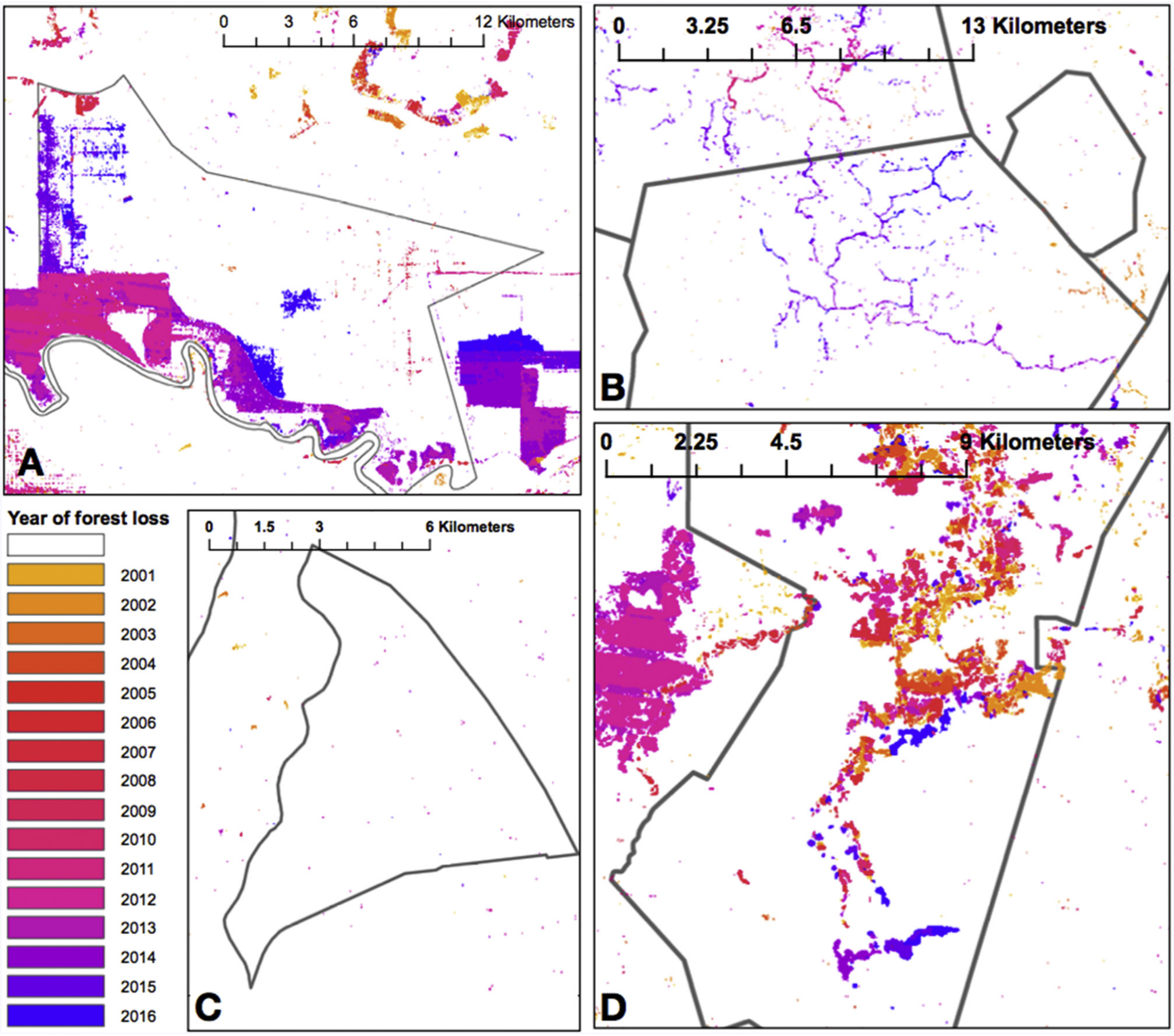

Fig. 1. Representative examples of different types of forest loss within Kalimantan's selective logging concessions, based on Global Forest Change data from 2001 to 2016 (Hansen et al., 2013). A – commodity-driven, industrial agriculture deforestation, typically for oil palm or acacia plantations. B – forest loss due to selective logging. C – no or natural forest loss. D – forest loss due to smallholder agriculture, such as rice and vegetable fields, or oil palm.

for dispersing Sunda clouded leopards, represented by connecting paths that unite all pairs of source points in a least-cost network (Macdonald et al., 2018b). For each concession, we calculated the mean and sum pixel values for the two data layers. Then, we ranked the concessions in terms of the highest mean and sum value.

3. Results

3.1. Forest loss in active and inactive concessions

Of the 170 selective logging concessions in East and North Kalimantan, we identified 49 as currently (2018) inactive (Table 2). The overall forest loss between 2001 and 2016, calculated as cumulative loss over the 16-year period, was higher in inactive concessions than in active ones (9.27% or 106,041 ha and 7.24% or 318,840 ha over 16 years, respectively, not taking into account forest gain, Fig. 2). A simple analysis of variance of $\log_{10}$ transformed overall forest loss rates shows that this difference is significant at the 0.05 level ($p = 0.046$). However, to fully understand this overall result, it is necessary to look at more subtle differences.

Until 2010, the forest loss in currently inactive and currently active concessions were, on average, nearly equal: 2.38% and 2.34%, respectively, over the 10 years between 2000 and 2010. After 2010, however, the average rate of forest loss across all concessions rose substantially, but more so in inactive concessions than in active ones (6.90% and 4.90% respectively, over the 6 years between 2011 and 2016, not taking any forest gain into account). A simple analysis of variance of $\log_{10}$ transformed 6-year forest loss rates shows that this difference is significant ($p = 0.041$).

The non-normal distribution of forest loss rates (hence the $\log_{10}$ transformation) reveals an important difference between active and inactive concessions, which contributed to the difference in mean forest loss rates (Fig. S1): within inactive concessions, there are more concessions with very low ($< 1\%$) forest loss rates than within active concessions, yet, there are also more concessions with very high forest loss rates compared to active concessions. The visual analysis of sources of deforestation sheds further light on the observed pattern.

Sources of deforestation differed substantially between active and inactive concessions. Of the 49 inactive concessions, 35% had no signs of anthropogenic deforestation between 2001 and 2016, compared to

Table 1
Candidate variables that might differ between active and inactive concessions.

Variable	Data layer used	Processing	Hypothesis
Elevation (m)	Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) at 90 m resolution	Mean elevation of all pixels within a concession	Forests at higher elevations are more likely to be inactive, as they have a lower timber stock than lowland forests (Sidiyasa, 2001) and are less accessible; road construction to reach such sites is more difficult/expensive.
Topography	SRTM DEM at 90 m resolution	Standard deviation and range of elevation of all pixels within a concession	Forests on steeper slopes are more likely to be inactive, as they have a lower timber stock; timber extraction on steep slopes is more difficult or even impossible in places.[b]
Area (ha)	Shapefile of logging concessions	Total area of each concession	Smaller concessions are more likely to be inactive, as they might be less profitable due to economies of scale related to selective logging.
Shape	Shapefile of logging concessions	Ratio of area (ha) to perimeter (km)	Concessions with complex shapes are more likely to become inactive because: (1) the complex shape indicates a complicated relationship with neighbours, perhaps indicating higher levels of social conflict; (2) complex shapes are more expensive to log in terms of building logging roads.
Distance to major city (km)	Shapefile of major cities in East and North Kalimantan	Most direct path between the centre of a concession to the nearest major city	Concessions that are farther away from major cities might be more likely to become inactive as the transport cost of logs might be higher.
Number of human settlements	Shapefile of settlements in East and North Kalimantan	Number of settlements within a 5 km buffer around the concession adjusted for concession area (including settlements within the concession)	High local human population density might be correlated with high levels of social conflict between communities and the company. Strongly conflicting demands on land may make a concession more likely to become inactive.
Forest loss[a]	Global Forest Loss data based on Landsat (Hansen et al., 2013)	Area of concession where forest loss occurred (% for each year from 2000 to 2016)	High forest loss due to selective logging in the past may indicate over-harvest, which could lead to low timber stock in the present. Low forest loss due to selective logging in the past could indicate naturally low timber stock. Inactive concessions might have higher forest loss stemming from illegal forest conversion for agriculture, due to lack of enforcement by an inactive company.

[a] This variable is not used in the logistic regression, because we do not know the year in which a concession became inactive. See section 'Sources of forest loss'.
[b] Whereas using SRTM DEM is known to result in a slope underestimate (Putz et al., 2018), the most recent ASTER data (recommended alternative) had > 10% of missing values for our study area due to high cloud cover.

17% of the 121 active concessions ($p = 0.017$, chi-squared = 5.734). These concessions, which we visually identified as not having any anthropogenic forest loss, had an average overall forest loss rate of < 1% over the 16-year period.

77% of active concessions had at least some signs of selective logging, i.e. forest loss through the legal, designated forest use in logging concessions (Fig. 1B, not to be confused with other types of deforestation, Fig. 1A,D), as opposed to 55% of inactive concessions ($p = 0.008$, chi-square = 6.939). Selective logging concessions are, by definition, open to selective logging, an activity that results in unavoidable forest loss (Fig. 1B) due to the removal of trees and the construction of roads, log landings, loggers' camps, and other infrastructure (Putz et al., 2012). Whereas there are, to our knowledge, no internationally accepted guidelines regarding how much forest loss, as measured through satellite imagery, is considered acceptable in selective logging operations, we found that across concessions that had forest loss *only* due to selective logging and associated infrastructure (Fig. 1B), the average forest loss rate was 2.86% in total over 16 years (not taking forest gain into account). The rate of forest loss purely due to selective logging did not differ between active and currently inactive concessions: 2.89% and 2.73% per 16 years, respectively. This suggests that those currently inactive logging concessions that did experience logging in the past must have been logged to a similar extent to currently active concessions, in terms of associated forest loss.

The percentage of concessions that had at least some forest loss due to smallholder agriculture did not differ substantially between active and inactive concessions (39% and 29% respectively). Similarly, there was only a small difference in the percentage of concessions that experienced at least some industry-driven deforestation for agriculture between active and inactive concessions (14% and 22% respectively). However, the average deforestation rate for concessions that we visually identified as having these illegal types of deforestation (anything other than selective logging) was higher in currently inactive concessions (21.94%) than in currently active ones (13.79%) over the 16 years. This difference was not statistically significant in a simple, $\log_{10}$ transformed analysis of variance, due to several outliers – small, active concessions that lost nearly all of their forest cover to other industries.

To summarize, whereas many inactive concessions did not suffer *any* forest loss at all, those inactive concessions that did lose forest suffered deforestation rates exceeding the rates observed in active concessions (Table 2, Fig. S1). Moreover, the high forest loss rates in those inactive concessions that did suffer deforestation were not because of the designated, legal activity (selective logging, Fig. 1B) but because of higher levels of smallholder and industrial encroachment (Fig. 1A,D, Table 2).

Finally, forest loss due to smallholders (Fig. 1D) was far more likely to occur in concessions that had also forest loss related to selective logging (Fig. 1B), $p = 0.0009$. In contrast, forest loss due to agroindustry was independent of the presence of selective logging ($p = 1$).

We emphasize that we do not know when exactly concessions became inactive and so it is impossible to establish whether inactivity caused, was correlated with, or was caused by higher rates of deforestation due to activities other than legal selective logging (see Discussion).

3.2. Characteristics of active and inactive concessions

Two variables were significantly correlated with the probability of a concession being inactive (Fig. 3): concessions with a higher mean elevation were more likely to be inactive ($p = 0.014$), and smaller concessions were more likely to be inactive ($p = 0.012$). The mean size and elevation for inactive concessions was 20,600 ha and 439 m a.s.l. versus 36,100 ha and 320 m a.s.l. for active concessions. (However, the single largest concession, 328,140 ha, was inactive.) The remaining variables (Table 1) were not significantly correlated with the

Table 2
Average forest loss rates for currently active and inactive logging concessions in East and North Kalimantan.

	Count (# concessions)	Total area (ha)	Selective logging present in % of concessions	Smallholder agriculture present in % of concessions	Industrial agriculture present in % of concessions	No or only natural deforestation present in % of concessions	Average % of forest lost per concessions cumulatively between 2000 and 2016	Average % of area lost per concessions cumulatively between 2000 and 2010	Average % of area lost per concessions cumulatively between 2011 and 2016
Active	121	4,403,873	77%* (i.e. 93 out of 121)	39%	14%	17%*	7.24*	2.34	4.90*
Inactive	49	1,143,916	55%*	29%	22%	35%*	9.27*	2.38	6.89*

* Significant difference ($p < 0.05$), please see results and methods for the specific statistical test.

probability of a concession being inactive.

3.3. Conservation value of inactive concessions

We compiled a list of the top ten inactive concessions in terms of their conservation value for the Bornean orangutan, top ten inactive concessions in terms of their conservation value for the Sunda clouded leopard, and top ten inactive concessions in terms of their conservation threat. Then, we looked at the overlap of these lists, identifying inactive concessions that ranked highly (within top ten) both in terms of conservation value and the level of threat (Figs. 4 and 5). Two inactive concessions appeared on all three lists (Figs. 4 and 5). (We cannot provide names of the concessions here for security or privacy reasons; individual requests should be addressed to the corresponding author.)

4. Discussion

Our results show that when logging concessions become inactive, there are both risks to and opportunities for biodiversity conservation. Overall, concessions that are currently identified as inactive had a higher forest loss rate over the last 16 years than those that are active. However, the fact that they are no longer active and therefore are no longer generating timber revenues may create opportunities for governments or NGOs to protect them from further disturbance.

4.1. Deforestation patterns in active and inactive timber concessions

Our results are not intuitive: The overall deforestation rate is higher in inactive concessions, even though fewer inactive concessions have experienced any type of forest loss compared with active ones. Moreover, selective logging – the activity legally permitted in logging concessions – leads to similar rates of forest loss in both active and currently inactive concessions, indicating that some other mode of forest destruction is disproportionately affecting the inactive concessions. Indeed, those inactive concessions that *have* suffered deforestation have, on average, a far higher forest loss rate due to activities other than selective logging, namely smallholder agriculture and industrial agriculture.

Active concessions are not immune to deforestation by smallholders or agroindustries: indeed, the proportion of active concessions that had at least some signs of such encroachments was about the same as the proportion of inactive concessions. Yet the amount of forest loss that results from these encroachments tends to be lower in active concessions than is the case for inactive concessions. This could mean that whether or not a smallholder initially decides to clear a patch of forest within a forestry concession may have little to do with the status (active or inactive) of the concession. However, the smallholder's activity may be more swiftly restricted or curbed in an active concession, resulting in an overall smaller amount of clearing. Similarly, deforestation by agroindustries is as likely to occur in active as in inactive concessions, likely due to inconsistencies in maps by the ministries regulating forestry and other commodities. However, active concessions may be better able to contest and halt such clearing before it becomes widespread.

We note that forest loss across all concessions rose substantially after 2010 (and this loss was starker for currently inactive concessions). A possible explanation for this is the exponential growth of the palm oil sector in Indonesia in the early 2010s, which resulted in 20 million ha of new plantations (Mukherjee and Sovacool, 2014), a development driven by an increasing global and domestic demand for palm oil for both food and biofuels (Susanti and Burgers, 2013). The palm-oil sector includes both industrial plantations and small-holder plantations.

Our findings have important consequences for conservation, in that the inactivity of forestry concessions can, counterintuitively, pose a greater risk to biodiversity than selective logging itself. It appears that active concessions provide a certain level of protection against other

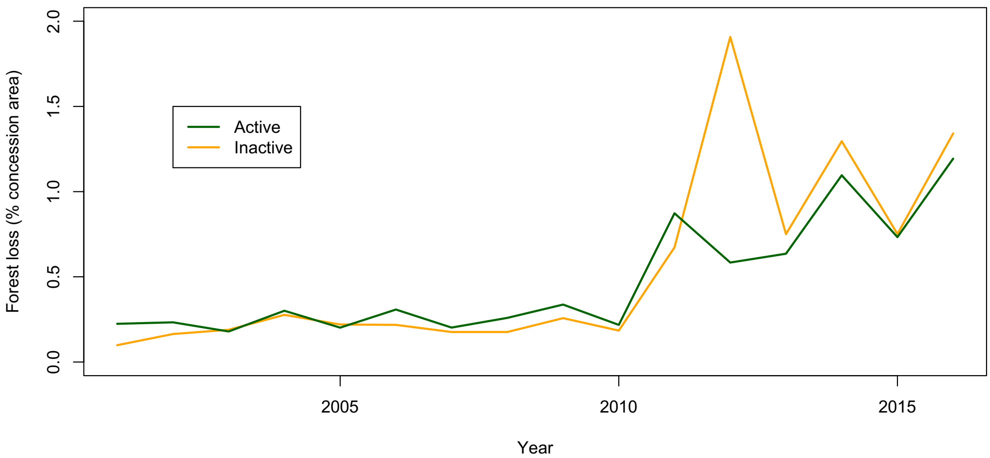

Fig. 2. Average rate of forest loss in currently active (green) and inactive (yellow) selective logging concessions in East and North Kalimantan, Indonesia. It is unknown when a concession became inactive, and whether any of the currently active concessions went through an inactive phase. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

types of forest loss. At first, this somewhat contravenes conventional wisdom, given that numerous studies have shown that selective logging 'opens' the forest to further deforestation by creating roads and making forested areas more accessible, e.g. (Meijaard et al., 2005; Asner et al., 2006; Laporte et al., 2007). Indeed, in our dataset, almost all cases of encroachment by smallholders appear in concessions with clear signs of selective logging activity. This could mean that, in East and North Kalimantan, as expected, forest tracts that are initially selectively logged are more likely to suffer from deforestation by smallholders and the agroindustry. However, once selective logging begins, the continuing presence of an active company can keep this forest loss in check. Concessions that are inactive or will shortly become inactive, *and where selective logging has already happened*, might therefore present a ticking 'deforestation time bomb'.

4.2. How do inactive concessions differ from active ones?

We found that smaller concessions and concessions at higher elevations in East and North Kalimantan are more likely to be inactive (Fig. 2) than larger, lower ones. This could be due to the lower profitability of smaller concessions – in Indonesia, the legal minimum logging rotation is 30 years (Minister of Forestry of the Republic of Indonesia, 2009; Romero et al., 2015). Typically, concessionaires divide their area into annual cutting blocks. In very small concessions, the annual cutting blocks may be too small to offset the planning, extraction, road building and maintenance costs associated with obtaining the timber. Transport costs may be higher in concessions that are at higher elevations.

Whereas logging managers mentioned social conflict anecdotally numerous times as a reason why concessions become inactive, we did not find a correlation between settlement density and the probability of a concession being inactive. This may be because settlement density is not a particularly good proxy for social conflict, or because social conflict with neighbouring communities is less important than other factors.

4.3. Inactive concessions on the frontier between natural forests and plantations

Several concessions had very high conservation value in terms of Bornean orangutan and Sunda clouded leopard habitat (Figs. 4, 5, and S1). Two concessions (A and B), were highly valuable for both species and at the same time were at high deforestation risk. These two concessions lie in the transition zone between lowland forest (suitable for Bornean orangutan) and montane forest (suitable for Sunda clouded leopard). Together with another group of inactive concessions (K, L, M), they also form a frontier between East Kalimantan's remaining natural forests (to the northwest) and forests allocated to, or already converted into, oil palm and acacia plantations (to the southeast). This frontier is also where one of the main Sunda clouded leopard dispersal corridors between North, East, and Central Kalimantan lies (Fig. 4C). Sunda clouded leopards have large territories and can travel as far as 250 km to establish a new territory (Macdonald et al., 2018b).

Indeed, Macdonald et al. (2018a, 2018b) predict that, under a

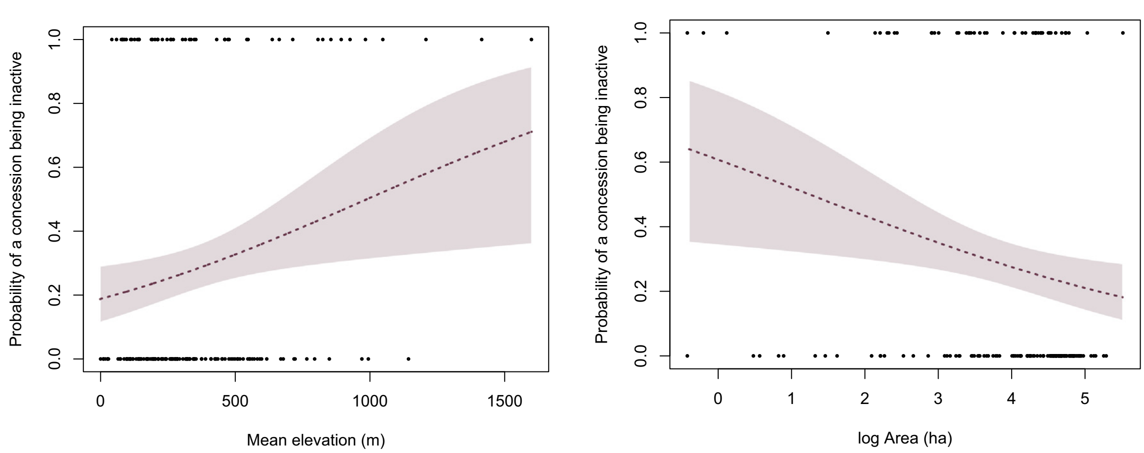

Fig. 3. Probability of a logging concession in East and North Kalimantan being inactive, as a function of elevation (left panel) and concession area (right panel). Black dots represent observations, pink dotted line represent logistic regression model fit and pink polygons represent 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

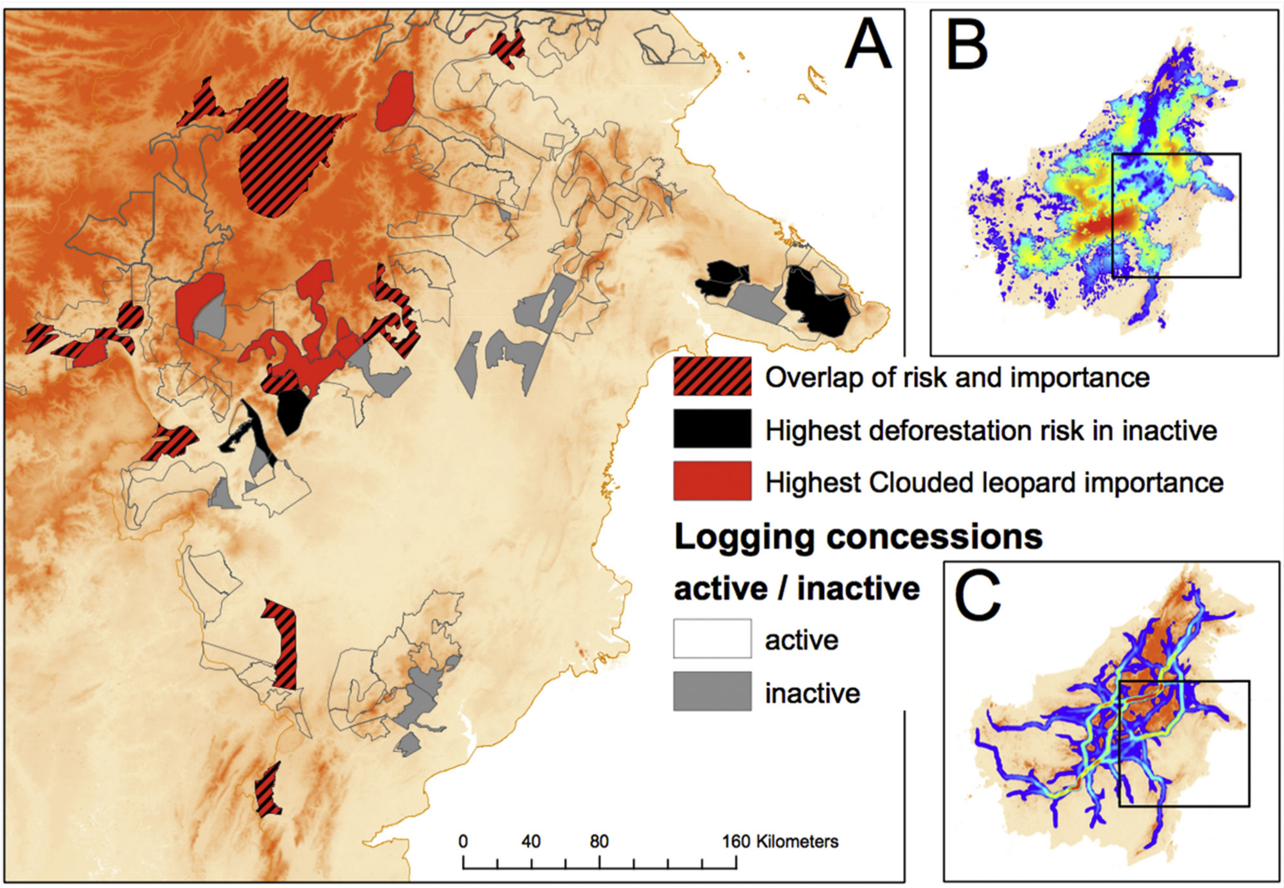

Fig. 4. A - Inactive selective logging concessions in East and North Kalimantan, Indonesia, that were ranked in the top ten in terms of deforestation risk in 2020 and in top ten in terms of either (B) estimated population density of Sunda clouded leopard in 2010 or (C) dispersal pathways (Macdonald et al., 2018b).

business-as-usual scenario, this corridor will be at very high risk of continuing deforestation in 2020, further fragmenting Sunda clouded leopard populations in Kalimantan. This particular corridor could, however, be maintained if the above-mentioned inactive concessions are kept as natural forests. Further north of these inactive concessions, the corridor crosses two Forest Stewardship Council-certified active concessions and a community protected forest (Hutan Lindung Wehea), all with relatively low forest loss rates. Further south, a potential disruption of this corridor could be prevented by encouraging sustainable timber management and preventing illegal deforestation within a narrow strip of active forestry concessions (N and O), which are currently surrounded by oil palm plantations in the north and south. A concerted conservation action focused on preventing deforestation within the inactive and active concessions along the forest/plantation frontier could have large benefits for Sunda clouded leopard and Bornean orangutan population viability, and, no doubt, for large number of other species.

4.4. Inactive concessions in Borneo's remaining wilderness

The largest selective logging concession in East and North Kalimantan combined (C), is currently inactive, and it spans the most important corridor for Sunda clouded leopard dispersal between northern and southern Borneo (Fig. 4). As other dispersal paths farther east and west will likely disappear due to deforestation, this central path may become even more important in the near future (Macdonald et al., 2018b). Whereas this concession does not suffer a high average forest loss risk per hectare, due to its large size, it is still in the top ten inactive concessions in terms of total hectares at conversion risk (Fig. S1). Parts of this concession contain low timber stocks (personal communications), and the concession as a whole is remote and features rugged terrain. We argue that this concession, due to its large size and comparative absence of forest disturbance, has enormous conservation value for Sunda clouded leopards and countless other species. Given the overall low probability of very large concessions being inactive (Fig. 2B), this concession is likely an outlier, and should be seen as a unique conservation opportunity.

5. Limitations

A fundamental question, which we are unable to answer due to the lack of publicly available data, is whether inactive concessions are more likely than active concessions to be formally re-allocated to other land uses, such as oil palm or pulp-and-paper concessions, i.e. removed from the forest estate and transferred to the agricultural estate (Gaveau et al., 2013). Such re-allocation is generally common in Kalimantan – from 2000 to 2010, for example, 25% of land allocated for timber extraction was re-allocated to plantation concessions (Gaveau et al., 2013) – and results in major losses of biodiversity. We were also unable to ascertain when exactly each concession became inactive, which would have been necessary in order to separate the cause and effect of inactivity. Finally, the number of concessions that we found to be inactive might be an underestimate: Several concessions that managers declared to be active showed no obvious sign of forest loss in the 16-year period between 2000 and 2016.

6. Conclusion

Inactive logging concessions in East and North Kalimantan are relatively common and collectively occupy a large area. Concessions that

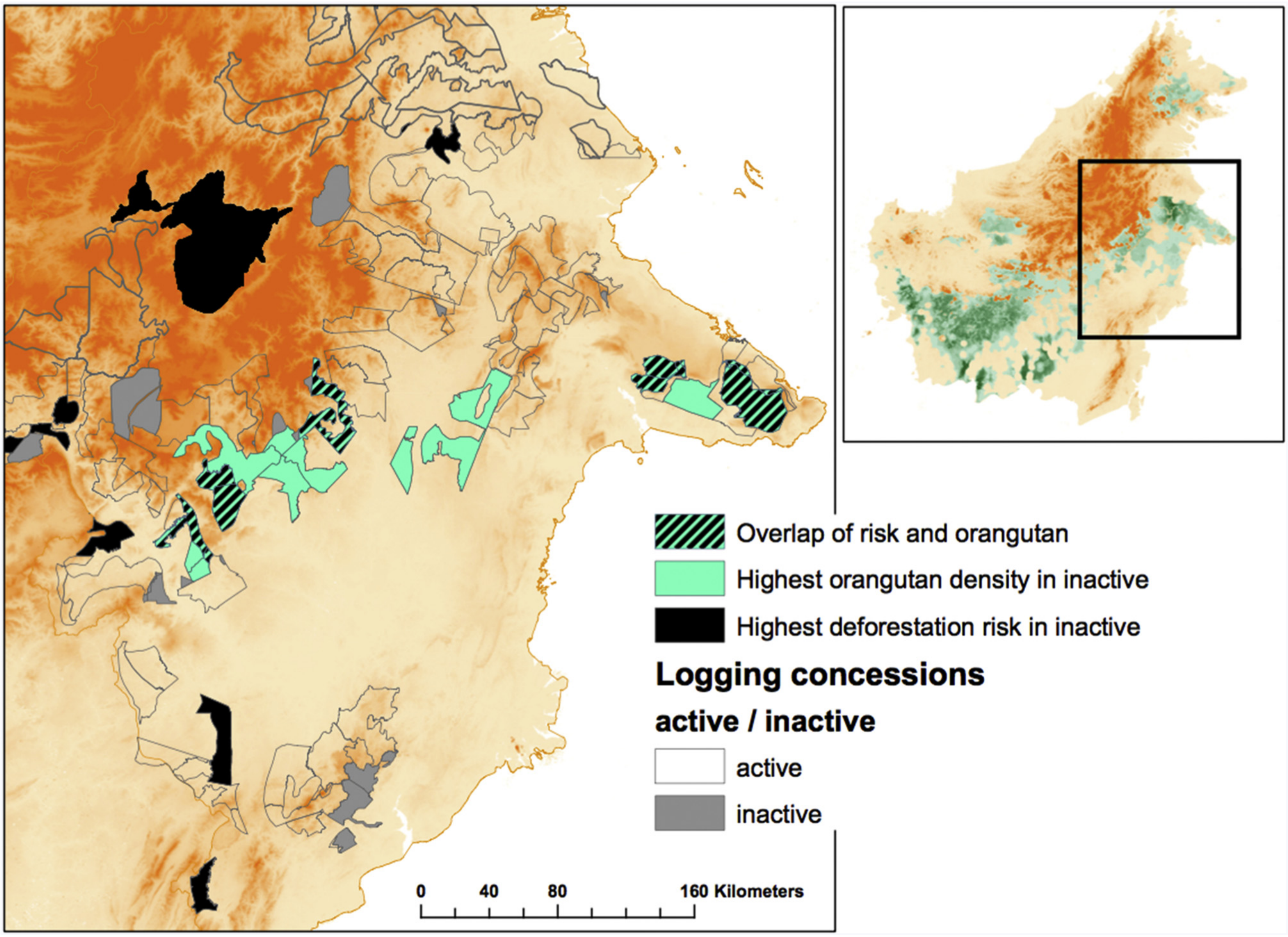

Fig. 5. Inactive selective logging concessions in East and North Kalimantan, Indonesia, that were ranked in the top ten in terms of deforestation risk in 2020 and in top ten in terms of Bornean orangutan's estimated population density. The smaller map shows the Bornean orangutan's range for the whole island of Borneo (Voigt et al., 2018).

are inactive, but where selective logging has already happened, might represent an insidious threat to biodiversity conservation: Our findings suggest that, in East and North Kalimantan at least, forests that are initially selectively logged are likely to suffer from deforestation due to smallholders and the agroindustry, but, once selective logging begins, the continuing presence of active companies appears to keep subsequent forest loss in check. In other words, the ceasing of selective logging operations in forestry concessions can, counterintuitively, pose a greater risk to biodiversity than the selective logging itself. (We hasten to add, however, that our results do not suggest that selective logging is preferable to no logging in sites that can be adequately protected once the logging ceases.)

We found that the inactivity of concessions is likely connected to lower profit margins that result from logging in smaller concessions at higher elevations. We identified several inactive concessions that, if maintained as natural forest, could significantly contribute to the conservation of the Sunda clouded leopard (Vulnerable) and Bornean orangutan (Critically Endangered) as well as other species sharing their habitat. Given the declining number and area of logging concessions in Indonesia, we have no doubt that this conservation opportunity is only a transient one and should be acted upon as quickly as possible.

Boom and bust logging cycles are hardly unique to Borneo and characterize timber operations in many other regions (Shearman et al., 2012). Thus, a ticking time bomb of deforestation in inactive forestry concessions may well be present elsewhere in the tropics, and we underscore the need to investigate such situations in order to be able to tip the balance away from the potential risks and towards true conservation gains: Shifts in land tenure involving commercial forestry operations should be examined worldwide in order to identify the best opportunities for biodiversity conservation and slowing climate change.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2019.108369.

Acknowledgements

ZB was funded by the NatureNet Science Fellowship and ZB and DW by the High Meadows Foundation.

We thank Herlina Hartanto, Johanna Buchner, David Macdonald, and the reviewer for useful inputs.

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