PALM TURMOIL

Spatial guidelines for a future (re)generation of palm oil plantations on Kalimantan

Douwe Douma 4451708
Arjan van Timmeren (first mentor)
Roberto Rocco (second mentor)
MSc Urbanism TUDelft
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Also, thank you to Robert Nottrop for saving the day being third delegate and Bob Ursum for providing me with (otherwise unobtainable) sources.

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ESA Copernicus II above Kalimantan palm oil expansion (2019)

ABSTRACT

Drastic oil palm plantation expansion has left Kalimantan low on lowland rainforest. Deforestation is accompanied by environmental consequences of establishing and operating a monoculture, as well as effects on biodiversity. Sacrificing spatial complexity comes at the costs of (microclimate) cooling potential, soil erosion, nutrient seepage, species richness and vulnerability to both flooding and fire (as climate change makes extreme conditions more likely).

Countermeasures against these threats focus on achieving more spatial complexity. The most important spatial interventions are intercropping, drainage ditch planting, boundary planting and restoring riparian buffers. Certifying produce as RSPO+ can steer implementation.

Key words: Kalimantan, oil palm, spatial plantation design, biodiversity, climate change

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1.1 INTRODUCTION

Over the past 50 years, the expansion of palm oil plantations has left Kalimantan deforested. The rise of oil palms can be explained by their high yields and cheap establishment costs (compared to other tropical crops). As the global demand for palm oil is expected to rise by a sevenfold by the year 2050, the expansion of plantations is likely to continue.

Despite increasing attention from the scientific community, research on oil palm is fragmented by discipline and largely ill-applicable. In this research, an integral analysis of environmental consequences concerning palm oil production, as well as its effects on biodiversity at first, followed by an overview of strategic countermeasures (in the spatial design part).

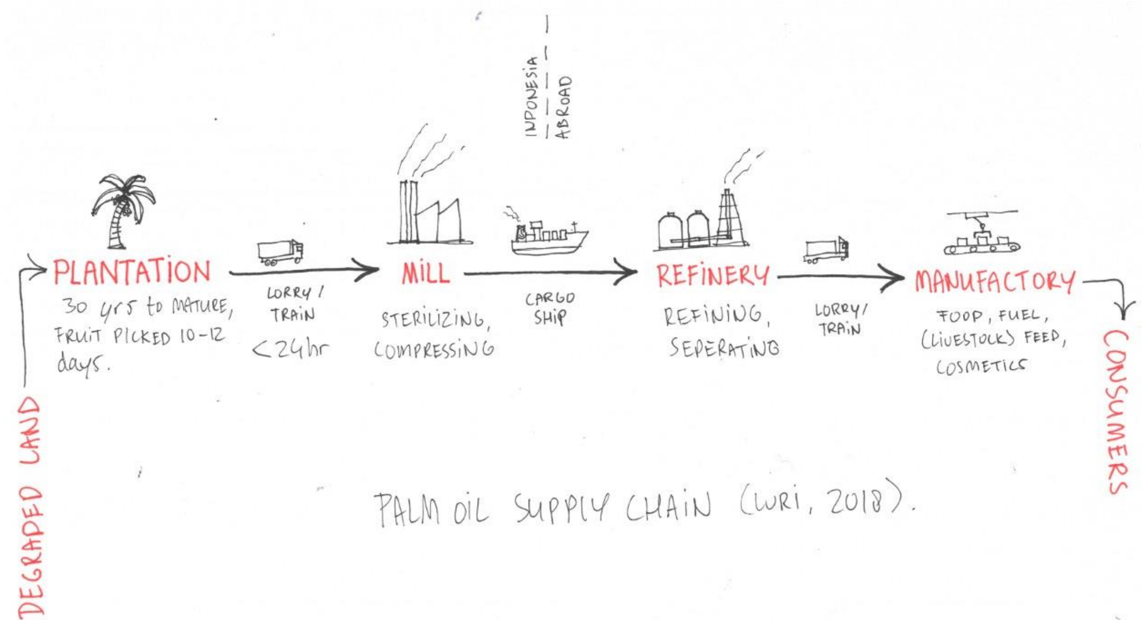
1.2 PLANTATION ESTABLISHMENT AND PRODUCTION

Oil palms grow on a range of soil types, including soils unsuitable for growing other crops (Corley & Tinker, 2003). According to the same source, it requires low fertilizer inputs per amount of produced oil (absolute amounts are large however) and is relatively resistant to pests and disease.

Establishing a palm oil plantation starts with land clearing (either mechanical or by fire). Slash-and-burn (used to clear pre-existing forest) obliterates aboveground biomass, understory vegetation and ground litter resulting in high environmental costs. Despite existing laws and policies prohibiting fire starting practices, it remains commonplace because it beneficially pre-fertilizes the soil. When biomass is set ablaze, only a fraction of carbon is retained in the soil while most is emitted into the air. Establishment on peat lands results in even higher carbon losses than from clearing alone, since the practice of drainage exposes the sub-surface levels of peat (flammable fuel) and causes irreversible subsidence and flooding. Oil palms cannot grow on waterlogged soils.

After initially constructing infrastructure, drainage ditches and terraces (slopes >25%) are built if required. Oil palm seedlings are then planted at densities of about 110-150 oil palms per hectare (Sheil et al., 2009). The palms mature and start bearing fruits after 2-3 years, production peaks between 9-18 years and will be maintained until 25-30 years (when the palms become inefficiently tall to harvest).

Proximity to processing mills is important, as harvested palm fruit bunches must be processed within 48 hours to prevent deterioration. At the processing mill, stalks are separated from the fruit (leaving empty fruit bunches as a waste product). The fruits are then pressed, producing liquid crude palm oil (mostly used in food), POME (palm oil mill effluent, another waste product) and solid 'press cake'. Press cake contains fibers, shells and kernels which are grounded and heated to extract palm kernel oil (used to produce detergents, cosmetics, and plastics). Leftover or 'waste' biomass can potentially be used to power the mill. Industrial plantations and plantation groups include their own processing mill (in a strategic location when clustered), which usually also takes in fruit bunches from cooperating smallholder plantations and third parties, making traceability to individual plantations near-impossible. Supply chain processes outside of Indonesia are disregarded as outside the scope of this project.



PALM OIL SUPPLY CHAIN (WRI, 2018).

1.3 GLOBAL MARKET DYNAMICS

Compared to other tropical or temperate oil crops, palm oil is the most profitable (Sung, 2016). The yield is high for the required amount of surface and labour, start-up costs are low and the global demand for palm oil is expected to rise much further, up to 447 million tons (almost a seven-fold) by the year 2050 (Afriyanti, Kroeze, & Saad, 2016).

In 2019, Indonesia produced over 42 million tons of palm oil, accounting for 58% of the global production (USDA Foreign Agricultural Service, 2021). Palm oil is an indispensable resource for a variety of global commodities, such as processed food (chocolate, ice cream, fries), livestock feed, biofuel, plastics, cosmetic products and clothes.

The Palm oil industry has benefitted the rural Indonesian economy in terms of household welfare and infrastructure, employing 7,5 million Indonesians (Sung, 2016). 85% of produced palm oil is exported, with an annual value of about 20 billion USD (Shigetomi, Ishimura, & Yamamoto, 2020). Between 35% (USDA Foreign Agricultural Service, 2021) and 37% (Gaveau, 2021) of Indonesian palm oil is grown on Kalimantan.

Deforestation rates for Indonesia peaked in 2016 and fell drastically between 2017-2019. This could be explained by El-Nino related drought in 2014-2016, causing widespread wildfire and the price of palm oil decreasing in 2017-2019. A price decline of 1% is associated with a 1.08% decrease in new industrial plantations and with a 0.68% decrease of forest loss (Gaveau, 2021). Government officials claim that the positive change is due to the implication of policy interventions (regarding the forest and peat moratorium).

According to Tiza Mafira (2019), one of the pioneers behind the ban on plastic bags in Indonesia, revenue from forestry is distributed as following over the governments: 20% is for the central government,16% for the regional and the remaining 64% of royalties is distributed equally between producing-districts and non-producing districts. Land-rent only goes to producing-districts (Mafira & Muluk, 2019).

The Netherlands is a major importer Palm oil, accounting for 15% of global trade in crude palm oil and 23% in palm oil cake. Largely unbeknown to the population, the Netherlands imports more palm oil per capita than any other country in the world, causing around 5500 m^2 of deforestation in Indonesia between the years 2005 and 2009 per capita (Shigetomi, Ishimura, & Yamamoto, 2020).

The imported amount of crude palm oil does not directly reflect on the actual consumption of palm oil in the Netherlands. Similar to coal, the Netherlands is a throughput (re-export) country to other countries in Western Europe (mainly Germany and Belgium, but also France), using its strategic geographical location and infrastructure for shipping. Import values of crude oil are close to export values of processed palm oil.

Malaysia exports most processed palm oil (11.3 million tonnes in 2009), while only accounting for a quarter of Indonesian crude oil production. Perhaps Indonesia focuses on exporting crude palm oil to avoid import tariffs upheld by the European Union (1.9% for crude compared to 9.45% for processed palm oil).

1.4 PROBLEM STATEMENT

While economically attractive, the expansion of palm oil plantations in Indonesia is controversial. On the island of Kalimantan, the practice is the main driver of deforestation, biodiversity loss and land degradation. Oil palm expansion directly accounted for 11% of Indonesian deforestation between 2000-2010 (Abood, 2014). Indirectly, palm oil expansion contributes to deforestation through several other pathways: (1) replacement of forests that were previously degraded by logging or fire; (2) joint economic ventures that first clear land for timber and then install palm plantations; (3) increasing access to remote forests through road infrastructure; and (4) displacement of food crops into forests (Fitzherbert, 2008).

The current way of producing palm oil will decimate primary tropical forest from the surface of Kalimantan. The emerging monoculture plantation landscape does not provide ecosystem services, shelter and food supply for the native biodiversity in the same way as primary forest would (Dislich C, 2017). Sacrificing spatial complexity apparently comes at the costs of (microclimate) cooling potential, soil erosion, nutrient seepage, species richness and vulnerability to both floods and fire. All these concerns are worsened by factoring in (autonomous) climate change.

Despite scientific agreement on the critical issues regarding palm oil cultivation, limited research is geared towards spatial analysis and (consequent) strategies. In order to offer alternatives to the local economy, this thesis tries to explore spatial ways by which palm oil can still be produced in large scale without less damage to the tropical forest. Although not an ideal solution, my thesis offers a possible pathway for sustainable agriculture that could be used across Indonesia.

1.5 RESEARCH QUESTIONS

The established problem statement calls for introducing spatial guidelines, so that new palm oil plantations are regenerative (and not detrimental) in terms of ecosystem services provided by the original landscape. This research goal is dissected into the following research questions:

MAIN RESEARCH QUESTION

How can palm oil plantations in Kalimantan spatially adapt to reinstate native biodiversity, while lowering environmental impact, within a changing climate?

SUB RESEARCH QUESTIONS

1 How do plantations currently operate, what relevant policies are in place and how does this translate spatially?
2 What impact does plantation expansion (and landscape homogeneity) have on local environment, biodiversity and climate?
3 How are plantations and stakeholders in turn affected by these changes, and autonomous climate change respectively?
4 What spatial measures would mitigate negative impact loops?
5 How can proposed strategies be implemented by key stakeholders?

1.6 METHODS

With the research questions formulated, the direction of the study becomes apparent. This chapter will elaborate further on introduced concepts and their distinctive relations, as well as to demarcate what kind of research will be executed and on what respective scale.

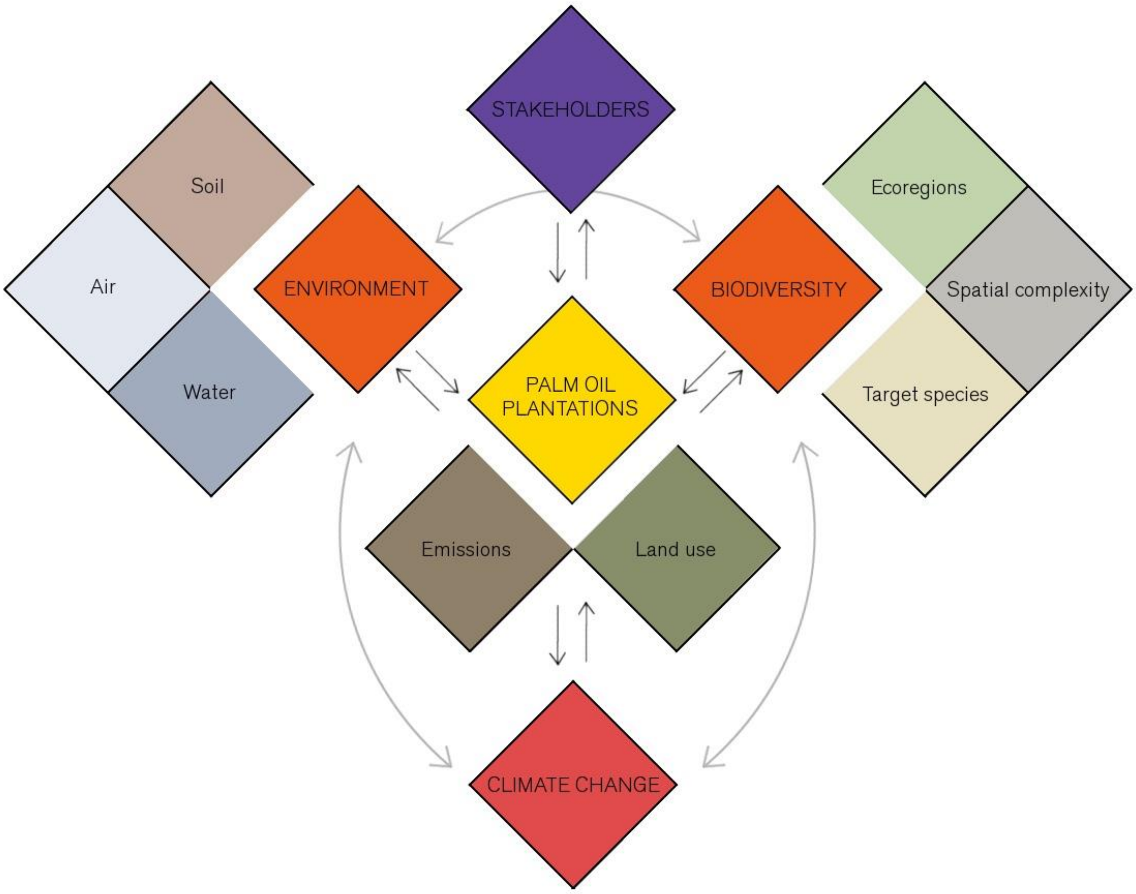


Figure 2. Conceptual framework (V4).

Whether palm oil plantations can be regarded as 'regenerative' hinges on how they interact with the following four variables: Environment, biodiversity, climate change and stakeholders. These variables are intertwined in the sense that they affect each other (regardless of palm oil interference).

Determining the influence of palm oil plantations on these variables is the main goal of the analysis part, in which the four variables have a separate chapter. Found literature provides general knowledge to palm oil plantations, not always specific to geological context. For this reason, a dozen of maps is made on the macro scale (of the whole island) to provide a spatial overview. Additionally, these maps were combined as layers in the synthesis, predicting where expansion will be most strategic (competed for) to determine what ecoregions are likely going to be targeted.

The expected outcome of the analysis is to find leverage points for spatially intervention. It is not a matter of maximizing environmental performance without any regard to production. Effective spatial guidelines balance financial costs, environmental performance and production. These design principles will be showcased in a design experiment, at the scale of a single plantation. Finally, a strategy will be given on how proposed changes (to the pilot plantation) can be implemented to palm oil plantations nationwide.

ANALYSIS

2.1 STAKEHOLDERS

According to (Contreras, Pas-ong, Lebel, King, & Mathieu, 2000), systems of governance affect political and social structures and processes, which in turn drive changes in forest conditions and land use. The system has a feedback loop, as shown in the figure below, since social and environmental outcomes influence 'institutional drivers of future change'.

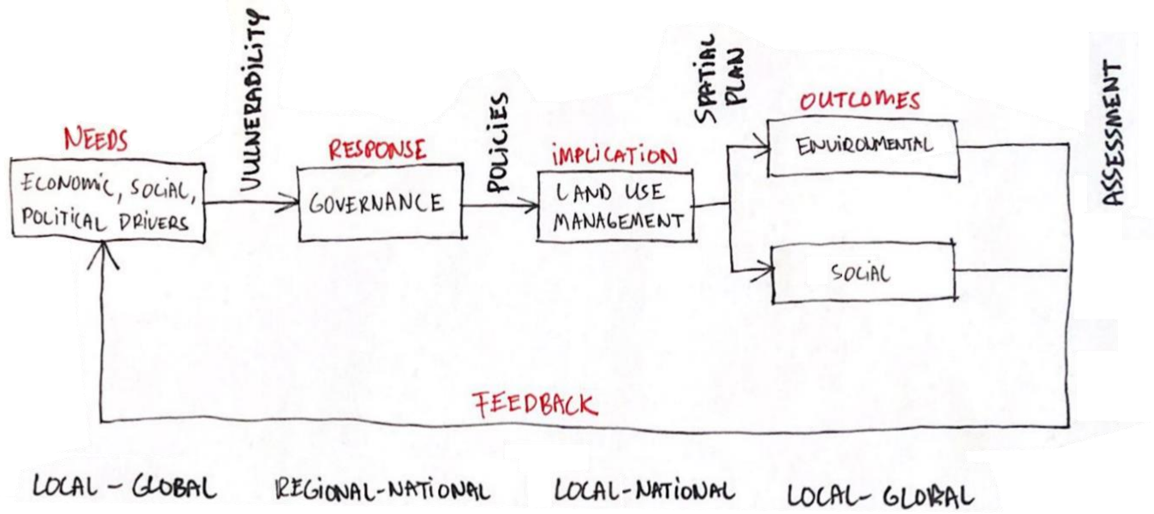


Figure 3 System of forest governance (Contreras, Pas-ong, Lebel, King, & Mathieu, 2000)*, edited.*

Main stakeholders in the Indonesian palm oil industry are plantation holders, manufacturers (secondary sector), (national and district) governments, local communities and certifiers (RSPO). These stakeholders are depicted in the power/interest matrix below, together with more supplementary stakeholders. The matrix indicates who benefits and who loses from a transition towards a more regenerative industry using coloured dots, and what power shifts are required (among stakeholders) to achieve certain transition using arrows.

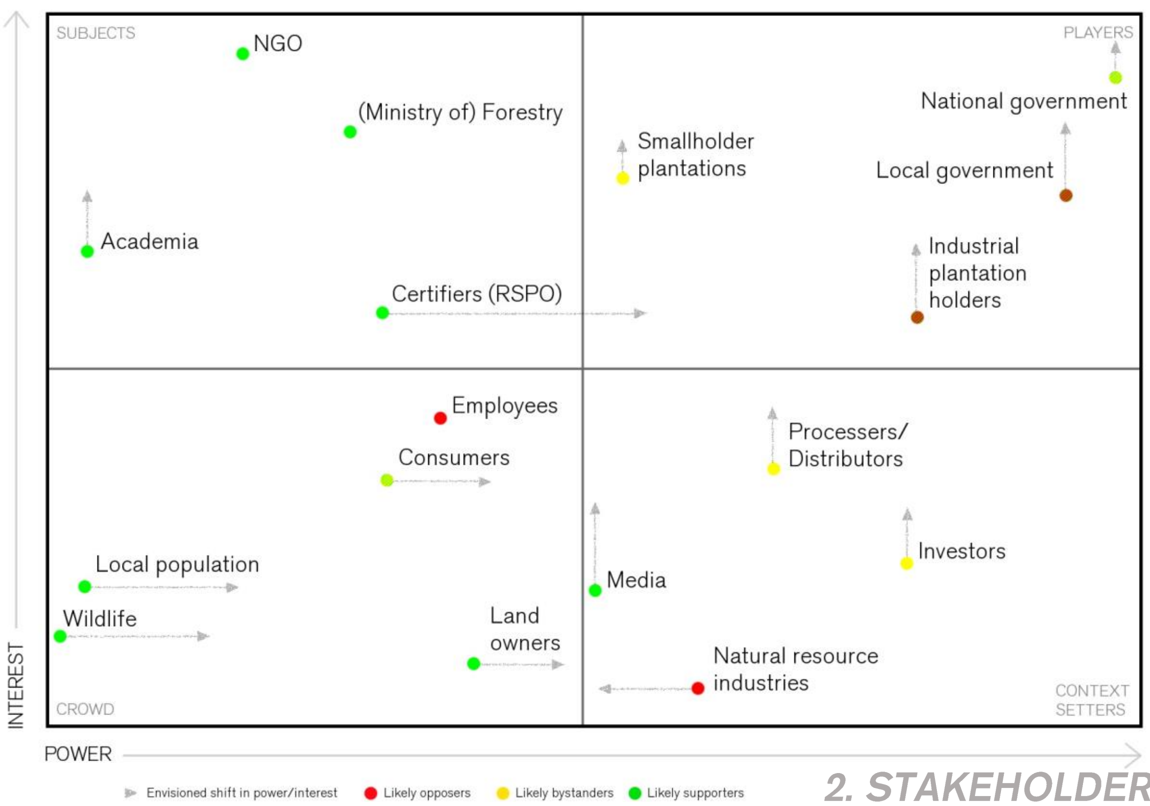


Figure 4. Power/interest matrix for the palm oil industry

Plantation holders can be sub classified into smallholder plantations (<25 ha) and industrial plantations (stretching up to hundreds of km^2, most are owned by companies, others are state-owned) or in RSPO-certified and uncertified plantations. While smallholder plantations are regarded to be more environmentally friendly than plantations of industrial scale (except for poaching rates, Azhar et al., 2015), it remains unclear whether RSPO-certified plantations outperform their non-certified counterparts from the viewpoint of biodiversity (S. Savilaakso, 2014). As to why smallholder plantations seem to be more biodiversity-friendly, this can possibly be explained by the more conservative use of pesticides, fertilizer, and heavy machinery, or by the fact that smallholder plantations are simply smaller: They are patchier and share more boundaries with other landscape types (because a smaller surface has characteristically more edge and less core, while industrial plantations are commonly surrounded by other plantations).

In the sustainability criteria of the RSPO for biodiversity, emphasis is put on areas that contain High Conservation Value (HCV). Generally, such features are assumed to be present if there are patches of natural forest in and around the plantation, or if the plantation borders natural habitats. Although HCV areas are important for biodiversity conservation, relatively few industrial plantations contain them (Azhar, et al., 2015) and even when present, plantation holders might lack the legal and technical means to effectively manage such areas. Research on spatial guidelines for (future) palm oil plantations can help overcome this problem.

The heterogeneity of farmland has been sidelined by the RSPO, despite being highly influential to biodiversity (Karp & A.J. Rominger, 2012). Animal species generally require a mix of landscape elements to suffice their biological needs (Forman & Godron, 1986). Additionally, landscape composition and configuration determine the ease and extent of wildlife movement between distinct habitats.

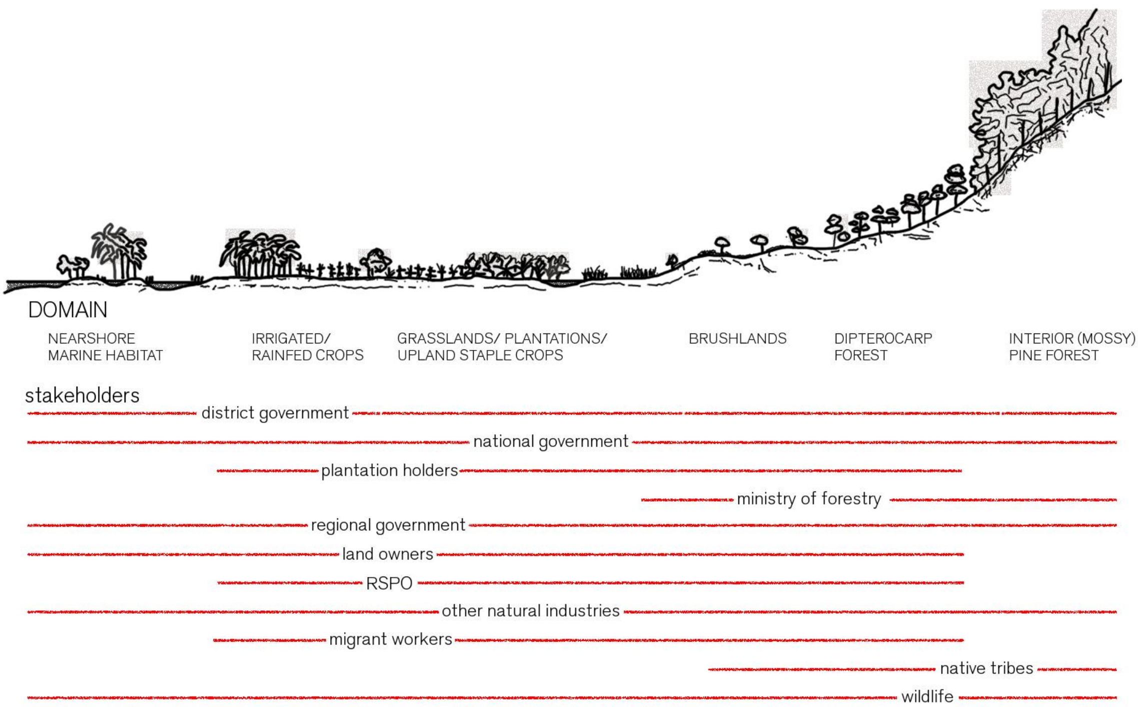


Figure 5. Cross section of Western Kalimantan with stakeholders and their relative domains. The listed stakeholders are put in order of apparent power.

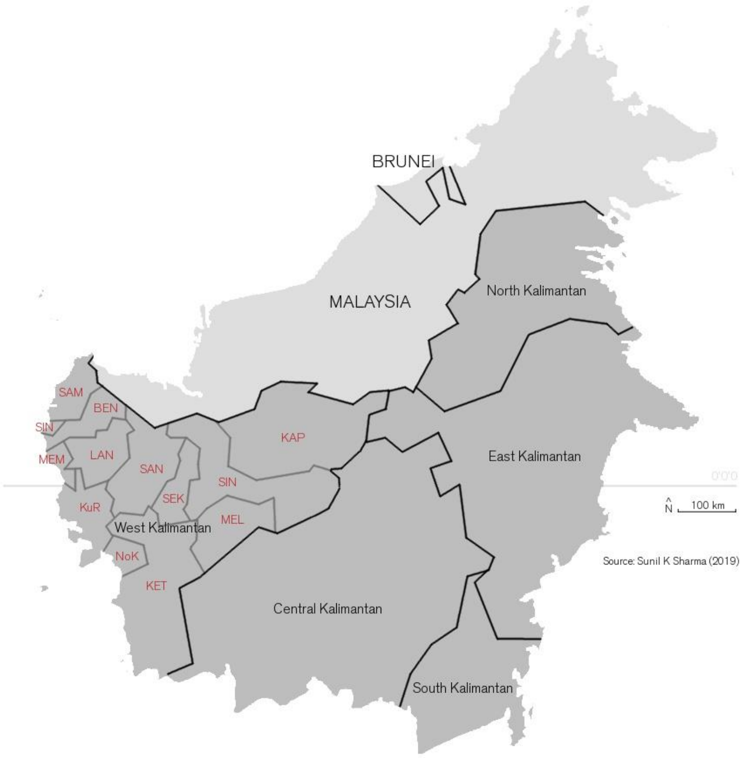


Figure 6. Countries, provinces and (abbreviated) districts on Borneo. The base map for many to follow.

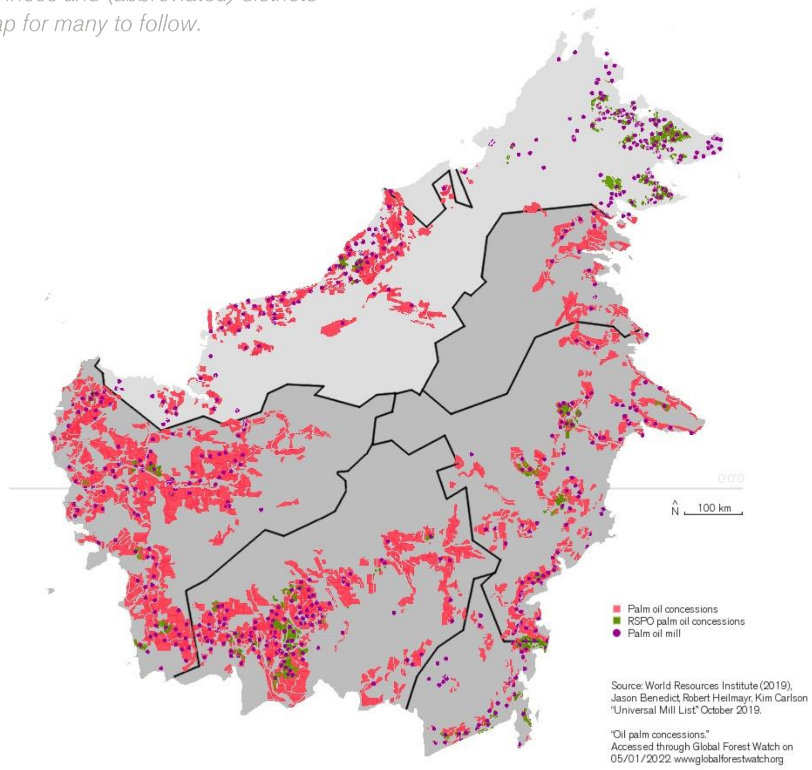


Figure 7. Palm oil concessions and mills. Note that the share of RSPO certified concessions is marginal. Areas indicated as concession differ between data from national and district governments and are not always developed as palm oil plantation. The opposite, plantations existing outside of concessions is obvious and can be checked using satellite images.

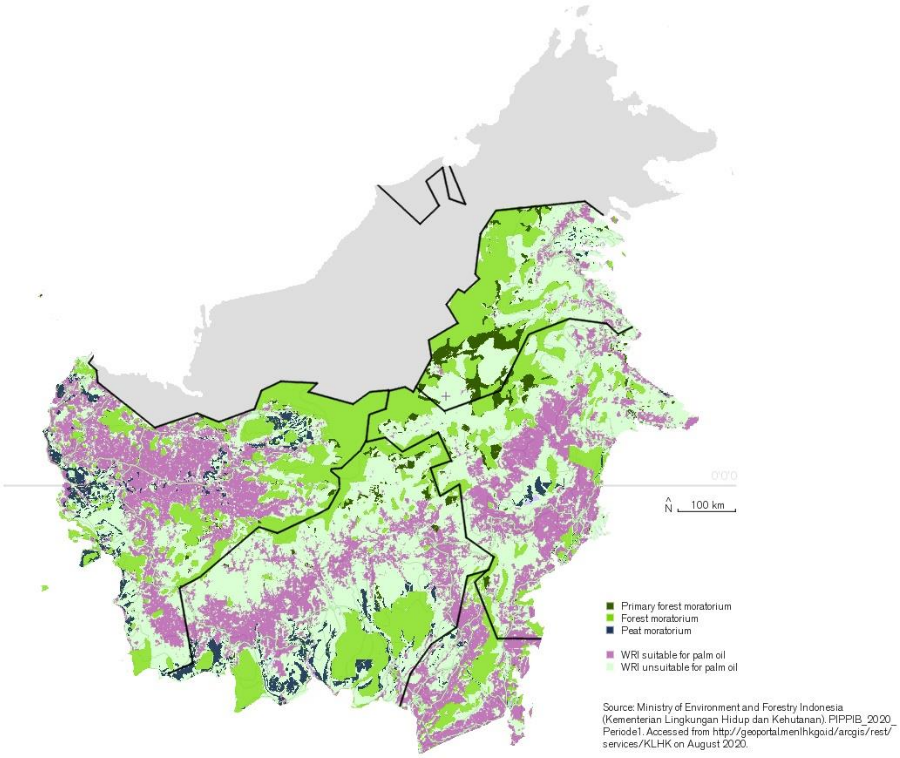


Figure 8. Soil deemed suitable by the WRI for palm oil cultivation is largely in accordance with concessions (figure above). Moratoriums have been introduced by the Indonesian government after the 2015 wildfires and can be interpreted as temporary extensions of conservation policies. They are about to expire.

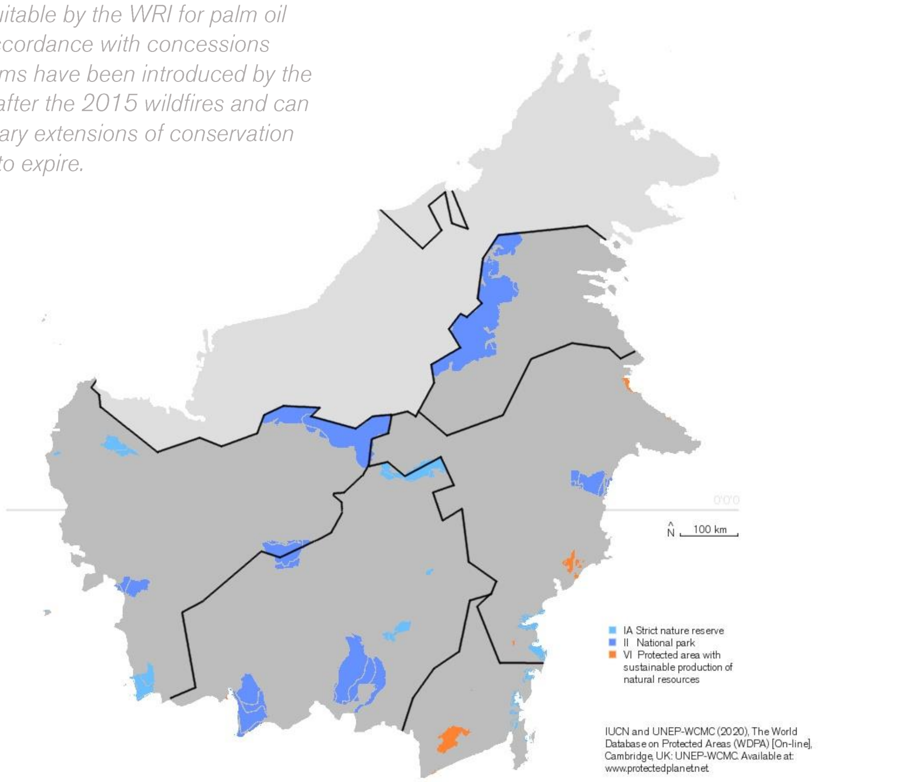


Figure 9. Permanently protected conservation areas. Note that they are located around the edges of the region(s) and represent not all rainforest and peat landscapes (map X in 3.1).

3.1 SOIL

Soil transportation and sedimentation processes are strongly influenced by water flowing within and between ecosystems. Thus, soil erosion depends on landscape configuration (position and shape), soil type and texture, climate, land cover and infiltration (Dislich C, 2017). Soil erosion can be quantified in the loss of soil organic carbon (SOC). Converting lowland forest to oil palm in the tropics leads to an average loss of 40% soil organic carbon stored in the (0,1m) top layer (van Straaten, 2015). Ten years after conversion, SOC values reverted to a stable state.

Providing sufficient soil nutrients (especially nitrogen and phosphorus) is essential for plant growth in both natural and agricultural ecosystems to maintain cycling between vegetation and soil. Tropical forest is characterized by high ecosystem productivity due to efficient cycling of rock derived phosphorus and biologically fixated nitrogen, even on weathered, nutrient-poor soils (Dislich C, 2017). Soil fertility (this effective cycling) reduces with the conversion to oil palm. Instead, the nutrients are released in a (peak) pulse wave during the burning phase. Oil palm, like any other plant has a relatively low uptake of nutrients before flowering stages, leaving stored nutrients susceptible to leaching and emission through the air, for as long as the palm matures.

Plantation holders can input nutrients using fertilizer, lime, nitrogen-fixing ground cover and compost/mulch (Dislich C, 2017). Predominantly mineral fertilizers are applied in large quantities on palm oil plantations. In the developing context of Kalimantan, the strive to maximise yields, combined with a limited farming tradition, can lead to fertilizer 'over-shoot' (Powlson, et al., 2011). If more fertilizer is applied to soil than is required to achieve maximum yield, nutrient cycles become imbalanced as nitrate and phosphorus remain unused in the soil. Over usage of fertilizer damages the environment, as it causes eutrophication of surface water and acidification of soil (Guo, et al., 2010). Approximately 20% of nitrogen-based fertilizers applied to agroecosystems seep into surrounding aquatic ecosystems (Galloway, 2004), causing algal growth, hypoxia and struggling fish populations in marine ecosystems.

Harvest and removal of palm biomass evidently leads to further nutrient losses. Each hectare of oil palm plantation on Sumatra, produces dry palm fronds containing 147 kg K, 125 kg N, 15kg Mg and 10kg P annually (Fairhurst, 1996). Leguminous cover crops and waste products like fronds (e.g. empty fruit bunches, POME and male inflorescences) can be used for mulch or compost, which breaks down and releases required nutrients gradually (unlike fertilizer). They can also be treated separately for bioenergy production (self-fuelling mills).

According to (Drinkwater, 2007), practices that enable plants and soil biotic communities to assimilate nitrogen can be used to reduce seepage of inorganic nitrogen (associated with overusing fertilizer). Two example practices are cover cropping and intercropping (explained further in the design chapter). In cover cropping, seeds are sowed in the off season to cleanse the soil from left-over nutrients of the previous growth cycle. Intercropping is cultivating a variety of crops in the same field at the same time, since different vegetation requires different (amounts of) nutrients at different stages extreme shortages or peak abundances of nutrients can be evaded. The effectiveness of riparian buffers around palm oil estates has not been proven.

Because plantations have less ground cover and less complex root structures compared to forest, shallow landslides (<3m soil depth) will occur more frequently in (particularly young) oil palm plantations (Bruijnzeel, 2004). Finally, soil should not be left bare: e.g. Mulching pathways reduces soil loss compared to uncovered paths by a threefold (Maene, 1979).

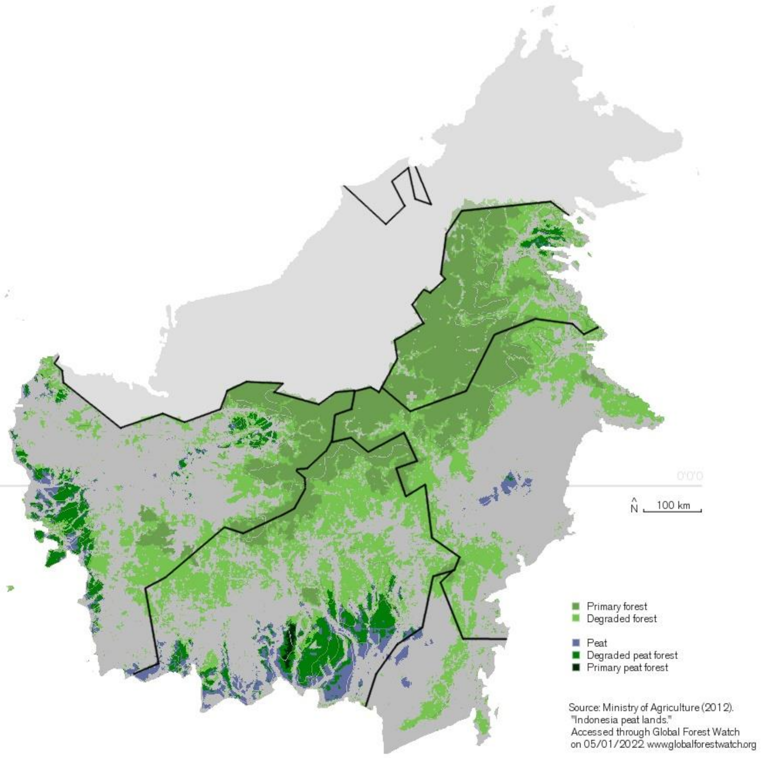


Figure 10. Peat lands, primary and secondary forest.

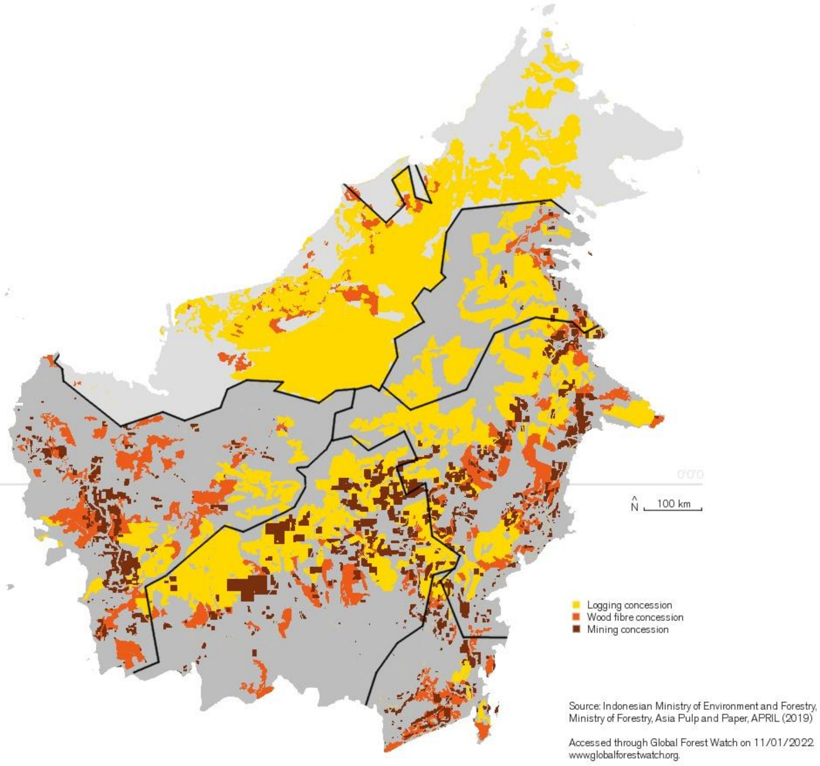


Figure 11. Other concessions, namely: logging, wood fibre and mining. These activities also attract oil palm as they clear forest, build infrastructure and remain only temporarily

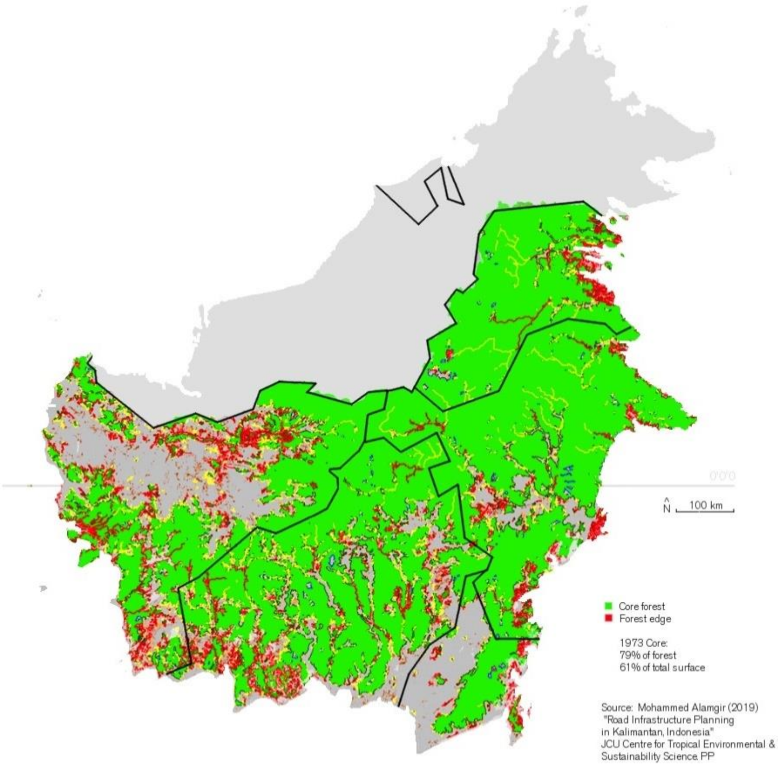


Figure 12. In 1973, 61% of Kalimantan's surface area was covered with primary forest.

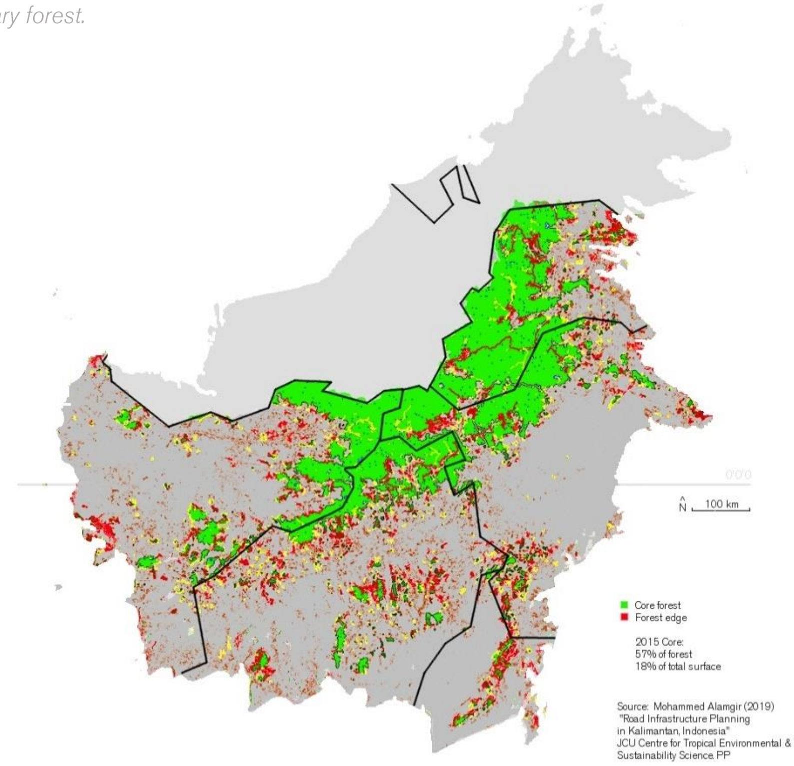


Figure 13. 50 years later, only 18% of the total surface remains core.

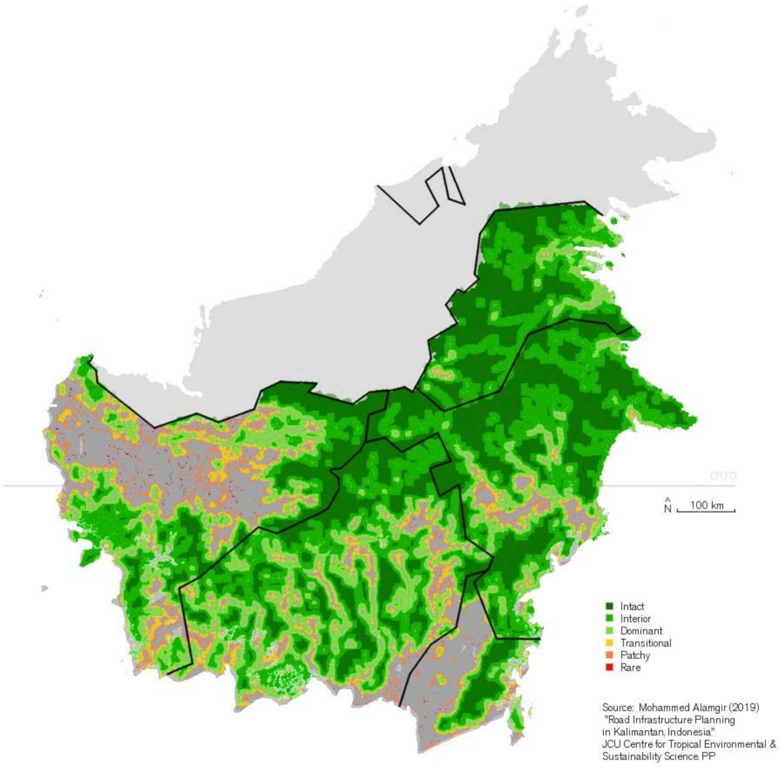


Figure 14. Fragmentation 1973

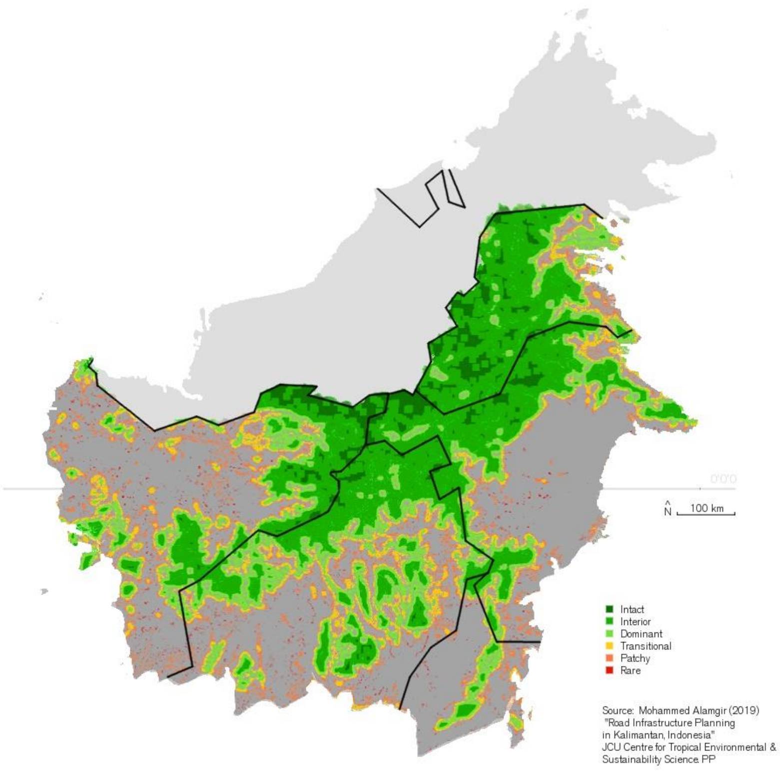


Figure 15. Fragmentation 2015. Besides losing surface area, forest typology is losing 'quality' too. Rather than being intact, patches are being isolated.

3.2 AIR

The next map (on page 24) shows the net GHG flux on the island of Kalimantan. Net GHG flux represents the balance between uptake and release of greenhouse gasses from processes in the soil and on the surface. Differences can be explained by land-use change (from forest to palm oil plantation), as the amount of carbon sequestrated by the active plantation does not add up to GHGs emitted during the land clearing (and subsequent) phases (Dislich C, 2017): Commonplace agroforestry on Kalimantan is a carbon source and not a carbon sink and contributes to climate change.

In comparison with CO_2, emissions of N_2O and CH_4 are modest even when factoring in their higher global warming potential. This is likely since most land clearing in Indonesia is done by fire (Kim et al., 2015) despite being outlawed, resulting in enormous releases of CO_2 from burning soil and vegetation (more so when the fire spreads beyond intention). Only a fraction of this burned biomass is retained in the local environment (charcoal) as most carbon will go up in smoke. Mean carbon losses are estimated on 702 ± 183 $MgCO_2$ ha^{-1} for conversions (forest to palm oil) on mineral soil and up to 3452 ± 1294 $MgCO_2$ ha^{-1} on peatland, both over a time span of 30 years (Fargione, 2008). Emissions from converting peatland are this high (that strict conservation is warranted), because peat stores a relatively high amount of carbon, which can directly be released when ignited (near impossible to extinguish) or indirectly through faster decomposition when earlier subsoil layers are exposed to oxygen.

Oil palm plantations significantly alter the ruling microclimate. Compared to forest, their canopies are less dense and the leaf area index is lower (the difference decreasing with the age of the plantation). In oil palm plantations on Kalimantan, mean maximum air temperatures were up $+6{,}5\circ C$ from primary forest and $+4\circ C$ in relation to logged forest (Hardwick, 2015). This effect stacks with the rising air temperature caused by climate change.

While forest usually can only burn during (extreme) moisture stress (Cochrane, 2003), palm oil plantations are more flammable as they are generally more exposed to elements and drier. Fragmentation (caused by large scale land-use change) elevates tree mortality around edges and in pockets. The assimilated dead branches and biomass are easily ignited and can start canopy fires. Roads and access bring along (potentially) fire-starting human activities.

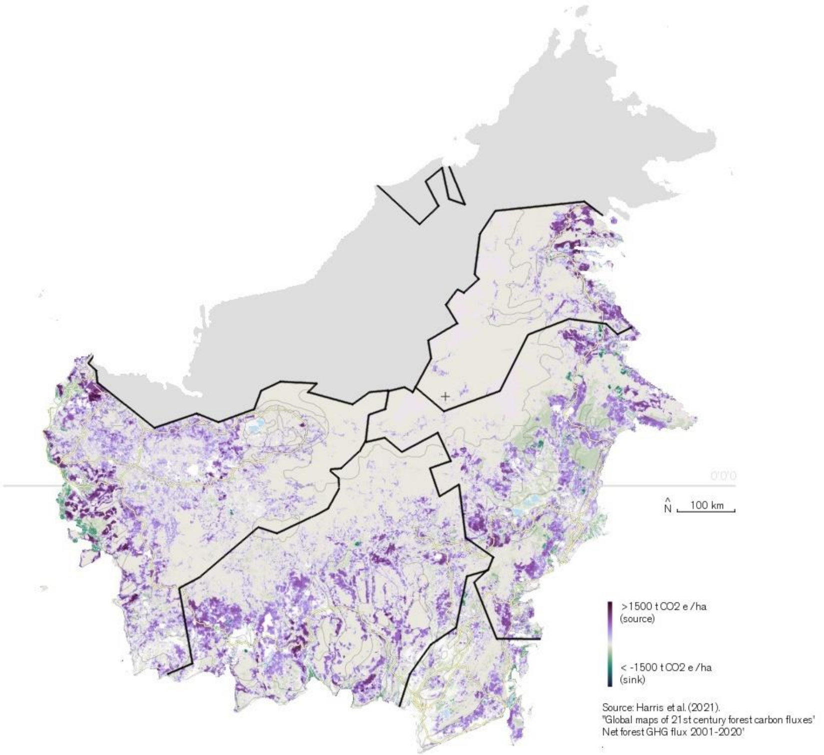


Figure 16. Net carbon-flux emitted 2001-2020. Purple areas indicate significant carbon sources, probably the result of deforestation. Little green (sinks) means not much forest was able to regrow.

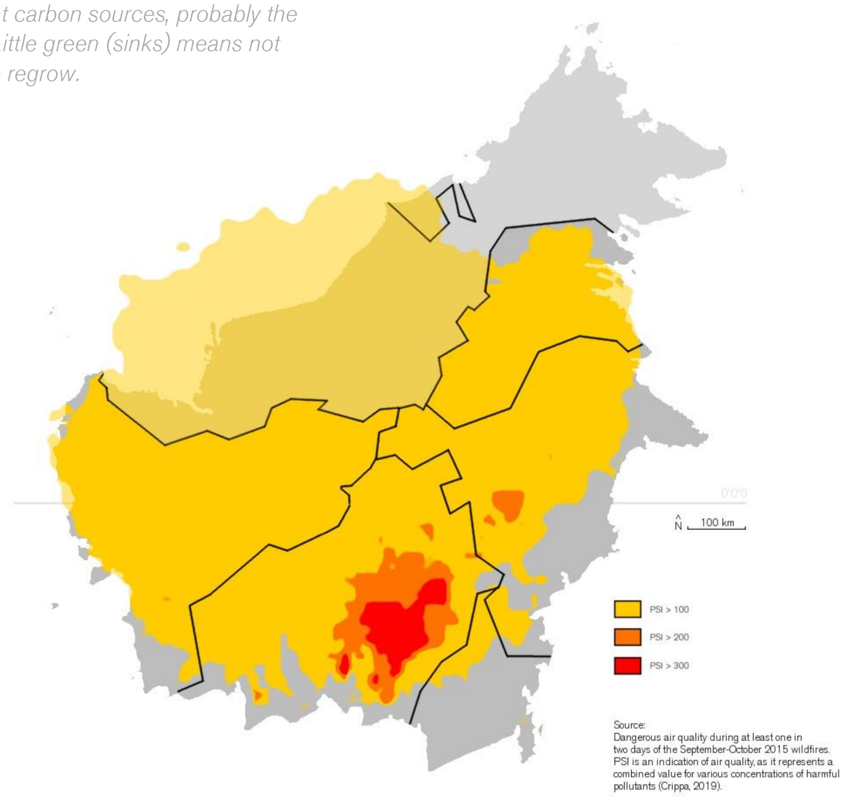


Figure 17. Hazardous PSI after the 2015-2016 wildfires. The pollutant standard index (PSI) is based on 24-hour average concentrations of particulate matter (PM_{10}), fine particulate matter ($PM_{2,5}$), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), Ozone (O_2) and carbon monoxide (CO) and can be used as an indication for air quality (Singapore National Environment Agency, 2021).

3.3 WATER

Palm oil related land-use change is associated with a decrease in water storage capacity, quality, and an increase in annual water yield (discharge). The magnitude of these effects tends to go down with plantation age, according to (Comte, 2012). Land clearing, the use of heavy machinery and traffic are causes of soil compaction, reducing the infiltration rate of the soil. This decreases the water storage (buffer) ability of the ecosystem, raising vulnerability to both floods and drought. Land clearing (using fire or drainage practices) additionally can cause the groundwater table to rise above the soil surface during periods of heavy rainfall, flooding the area from below (a phenomenon called soil subsidence). Flood plains and similar sites prone to flooding should be avoided when establishing plantations, as oil palm is unable to thrive in waterlogged conditions (Abram, 2014).

Surface run-off, in case of reduced infiltration, means the ecosystem must discharge more water in a shorter period and thus flooding is imminent. Furthermore, the faster flow of water means more sediment will be taken along: A threat to water quality and marine biodiversity.

Water yield (the amount of water flowing out of the system) is significantly higher in young palm oil plantations than forest, up to 420% according to a relatively old study by the Malaysian Department of Irrigation and Drainage (1989) due to 'less evapotranspiration'. Such numbers can also be explained by intensive irrigation, potentially causing streamflow depletion in dry periods. Evapotranspiration rates of mature plantations are in the same range as those of forested counterparts (Comte, 2012).

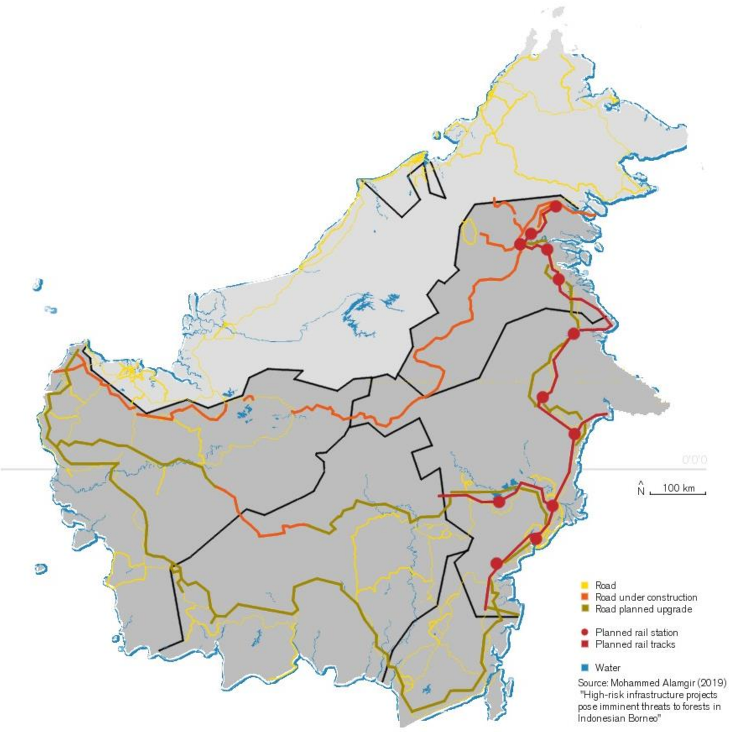


Figure 18. Infrastructure on Kalimantan. The rivers are naturally shaped and connect interior mountains with ocean. Train tracks prepare for the capital being moved to Eastern-Kalimantan due to the unsustainability of Jakarta. Roads under construction into the interior could threaten remaining primary forest by bringing palm oil expansion along.

3.4 CLIMATE (CHANGE)

Kalimantan enjoys a tropical climate (high temperatures and high precipitation) all year around. The dry season (may-sept) is not that dry (precipitation does not drop below 180mm) compared to regions further from the equator. These conditions are optimal for cultivating palm oil.

While Southern and Eastern Indonesia is expected to receive less rainfall throughout the year in the future, the North and West (including Kalimantan) likely will see more (excessive) rainfall, especially during monsoon season (potentially causing flooding) (Sa'adi, Shahid, & Sanusi Shiru, 2021).

The Southeast Asian Seas region (SAS, Indonesia belongs to) is often referred to as the 'coral triangle' (Veron, 2009) due to being the world's most biodiverse marine area. The westward flow of the North Equatorial current and the Indonesian throughflow (Hoegh-Guldberg, 2014) come together and interact here. Trends over the last 50 years show a significant warming of sea surface temperature (+0.8C) and sea level (Hoegh-Guldberg, 2014). The elevated temperature has driven mass coral bleaching and mortality events since the early 1980's, and can be linked with a high confidence to anthropogenic climate change (Hoegh-Guldberg, 2014). Additionally, coral reefs are prone to local stresses such as (excessive) fishing and declining water quality. Air temperature increases could have a similar effect on life on land.

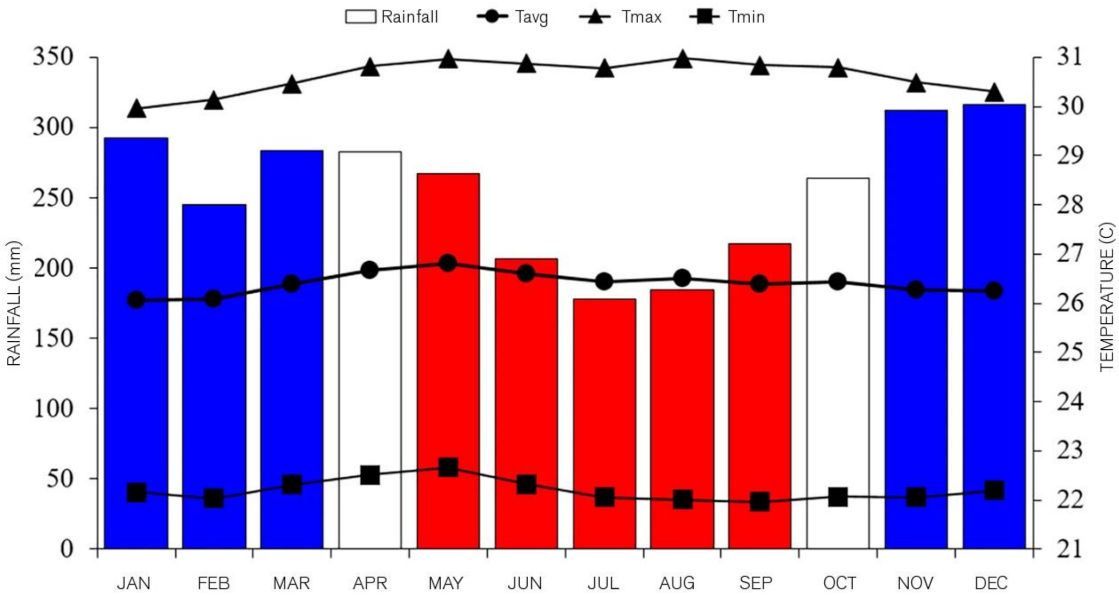


Figure 19. Bornean climate throughout the year 2016 (Sa'adi, Shahid, & Sanusi Shiru, 2021).

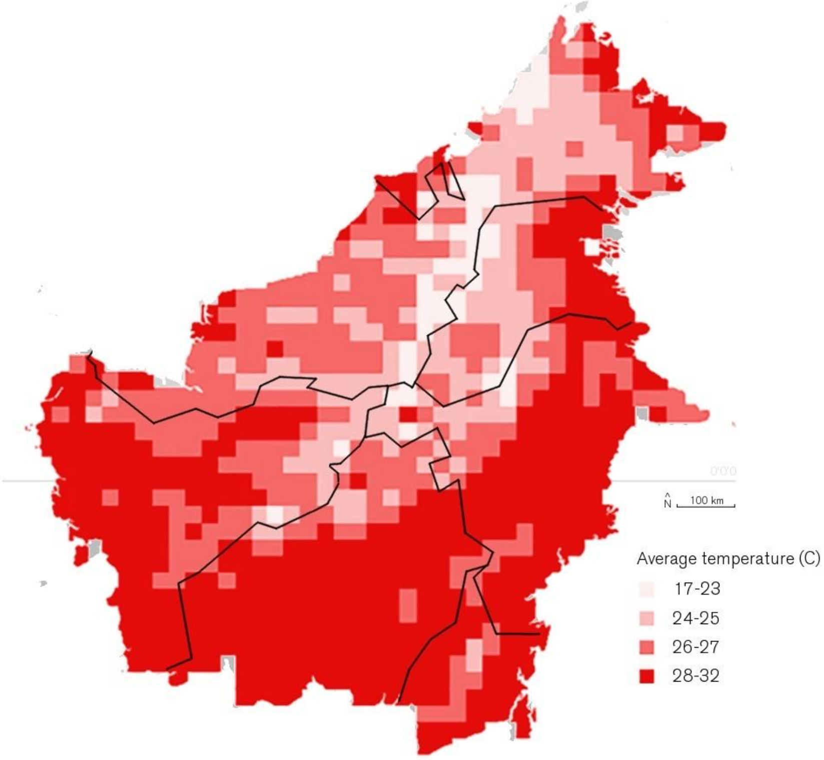


Figure 20. Average temperatures in Celsius.
(Sa'adi, Shahid, & Sanusi Shiru, 2021).

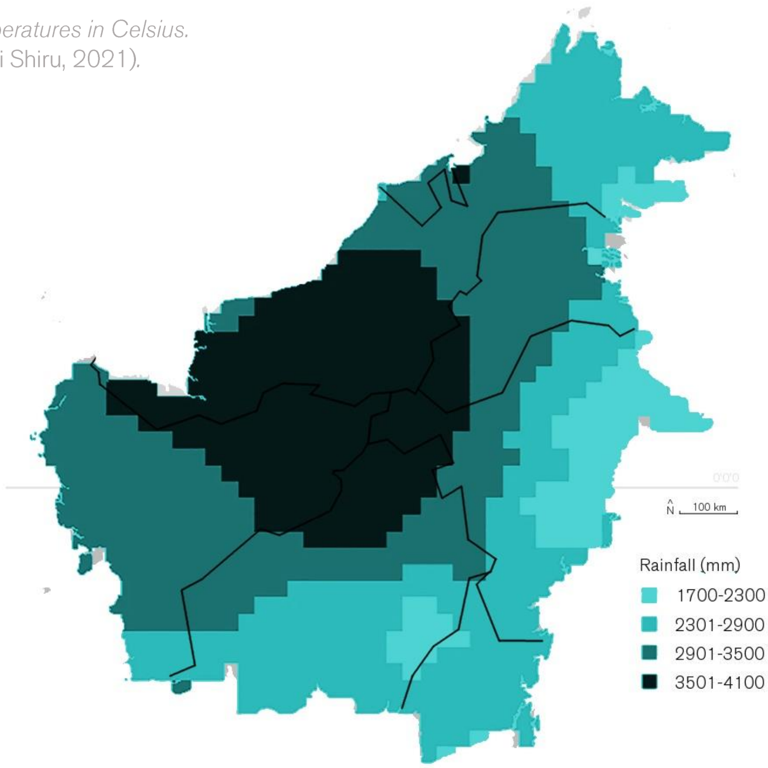


Figure 21. Average rainfall in millimetres Here, differences per region are significant (Sa'adi, Shahid, & Sanusi Shiru, 2021).

3.5 CONCLUSION

Between 1973 and 2015, the share of Kalimantan's surface area covered with primary forest went down from 61% to just 18%. It is estimated that palm oil plantation expansion causes half of this deforestation.

Oil palm plantations significantly alter the ruling microclimate. Compared to forest, their canopies are less dense and the leaf area index is lower. In oil palm plantations on Kalimantan, mean maximum air temperatures were up +6,5 ◦C from primary forest and +4 ◦C in relation to logged forest (Hardwick et al., 2015). While forest usually can only burn during (extreme) moisture stress (Cochrane, 2003), palm oil plantations are more flammable as they are generally more exposed to elements and drier. Fragmentation (caused by large scale land-use change) elevates tree mortality around edges and in pockets. The assimilated dead branches and biomass are easily ignited and can start canopy fires.

Land clearing, the use of heavy machinery and traffic are causes of soil compaction, reducing the infiltration rate of the soil. This decreases the water storage (buffer) ability of the ecosystem, raising vulnerability to both floods and drought. Land clearing (using fire or drainage practices) additionally can cause the groundwater table to rise above the soil surface during periods of heavy rainfall, flooding the area from below (a phenomenon called soil subsidence).

The use of fertilizer is another reason for environmental concern. This could be alleviated by mulching or composting waste biomass produced by the plantation. Instead of collection at mills, where biomass or manure first needs to be transported to (with empty lorries returning) the nutrients originating from a plantation should be kept in the system to achieve circularity. To stimulate soil biota, composting should be done in anaerobic conditions, possibly under water, roof or plastic. Mixing dry biomass with wet dredging soil brings enzymes in, characterized by their produced heat and damp. Cover cropping and intercropping (varying nutrient demand) reduces standing pools of nutrient 'overshoot'. Mulched pathways have a third of the soil loss compared to pathways left bare.

The climate in Western-Kalimantan is consistently warm and wet. Southern and Eastern regions receive less rainfall compared to the rest of the island. Climate change is expected to increase precipitation island wide.

4.1 BIODIVERSITY AND SPATIAL COMPLEXITY

Defined as a multifaceted concept (Dislich C, 2017), biodiversity refers to diversity of life forms on different levels of organization (from genes, to species and entire ecosystems). As such, biodiversity is not an ecosystem function itself, but of importance to many ecosystem functions. Providing a habitat suitable to the needs of species is required for their (and offspring) survival.

Research on plantation biodiversity is generally focused on species richness in small sampling plots. Conversion of forest to oil palm represents a threat to biodiversity, as this negatively impacts available (viable) habitat and configuration. The vegetation structure simplifies, negatively impacting the ruling microclimate and access to species (to be hunted or removed when considered a pest). The canopy of oil palm plantations is lower and monotonous, as other plant forms (such as lianas) are not tolerated (Foster et al., 2011). The understory of oil palms in a plantation differs from forest in the sense that it is generally hotter, drier, and less shaded: Unconventional conditions for many forest species (Hardwick et al., 2015). Human activity and propagule pressure (i.e. the share of non-native species in a specific area) causes plantations to be heavier invested with exotic and weedy species, incentivizing the use of pesticides. All these aspects indicate declining survival chances for native species (many threatened), even before factoring in expected climate change.

Biodiversity studies so far indeed show a decline in species richness in oil palm plantations compared to the original forest, counting: birds, mammals, insects, reptiles, fungi, and plants (made visible in the figure below). Additionally, the species found present were more frequently (ordinary) generalist species, not specific to the native forest habitat. When averaging across all taxa, only 15% of primary forest species also occur in oil palm plantations (Fitzherbert, 2008).

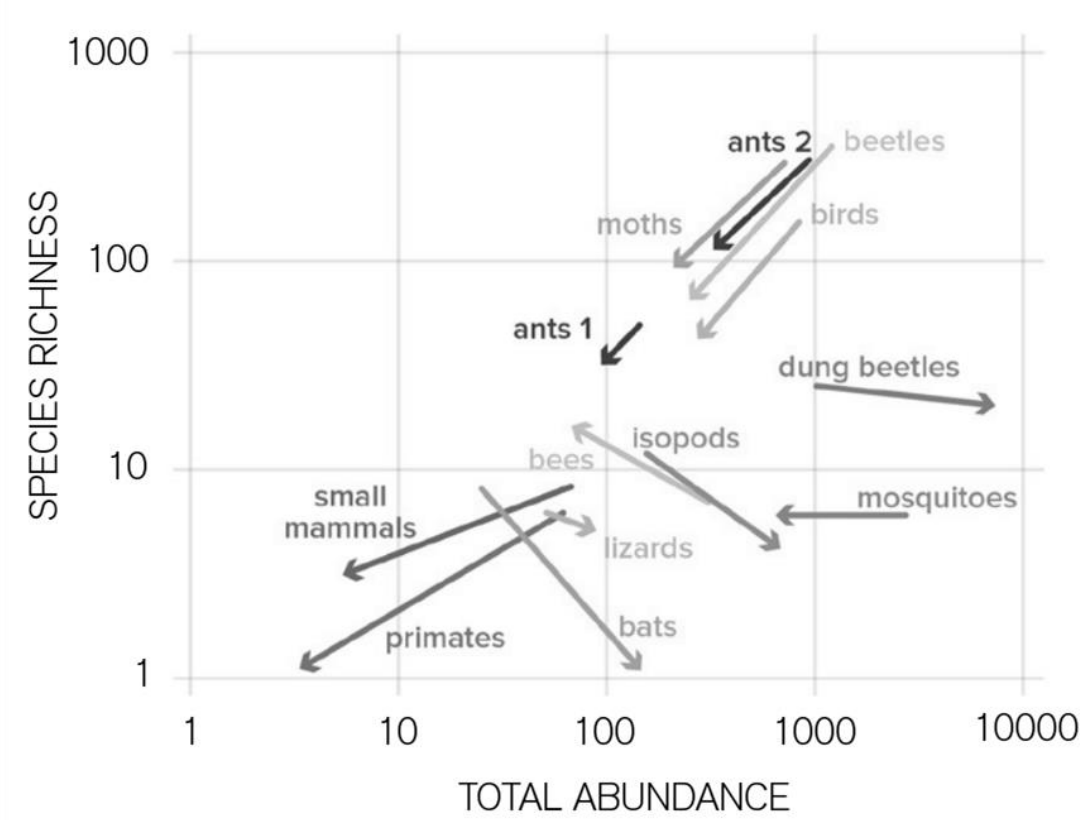


Figure 22. Impact of converting forest into oil palm on species abundance and diversity. Edited from (Meijaard, Sheil, Wich, & Garcia-Ulloa, 2018)

Danielsen (2009) concludes that only 23% of vertebrates and 31% of invertebrates is retained after conversation. Especially the (reduction of) functional biodiversity, e.g. pollinating (dung beetles) and indicator bird species is a threat and requires further study.

Organism richness (the oppsite) can become a problem (pests or diseases) if economic damage is significant. Trunk borers, defoliators, frugivores, plant suckers and wilt diseases pose the biggest pest treat to oil palm plantations. Biological control on the simple monoculture plantations is unsuitable, as limited food and habitat options curb diversity of species. Compared to forest, (insectivorous) birds and bats have trouble adapting to living conditions in and around oil palm plantations (Shafie et al., 2012). Fungi, entomopathogenic viruses and bacteria, barn owls and snakes are all used by plantation holders to control a variety of pests. The manual release of such control agents in oil palm plantations can have benefits for surrounding forest threatened by the same pests (Dislich C, 2017). Letting pigs graze in plantations can foster the opposite effect: an invasion of exotic species into nearby forest, such as the *Clidemia hirta* shrub (Fujinuma & Harrison, 2012).

The introduction of native forest understory can contribute to species richness and abundance of pollinating insects (increasing decomposition rates of organic matter) in plantations (Chung et al., 2000). Weevils (*Elaeidobius kamerunicus*) have been introduced to Southeast Asia (Vaknin, 2012) as a pollinating insect, without yield would be significantly lower. Relying on a single entity for pollination is risky, but so is introducing additional (exotic) weevil species (Foster et al., 2012). According to Dhileepan (1994), wind is of secondary importance for palm oil pollination (only relevant in the absence of pollinating insects). Understory weeds do not require cross-pollination due to autogamy. Habitat loss, fragmentation (isolation of habitat) and wildfire pollution reduces pollinator population and ability to function.

Efforts geared towards improving biodiversity on oil palm plantations hinge on achieving spatial complexity (Koh et al., 2009). Plantations need encouragement to vary in canopy height, canopy coverage, undercover plants, in addition to tolerating tree (other than the oil palm) and epiphytes species within planted area. Unplanted areas (especially adjacent to forest) are maximized by maintaining native vegetation (Dislich C, 2017)

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Figure 23. Barn owl guarding a plantation in Sumatra. © Erik Solheim, edited.

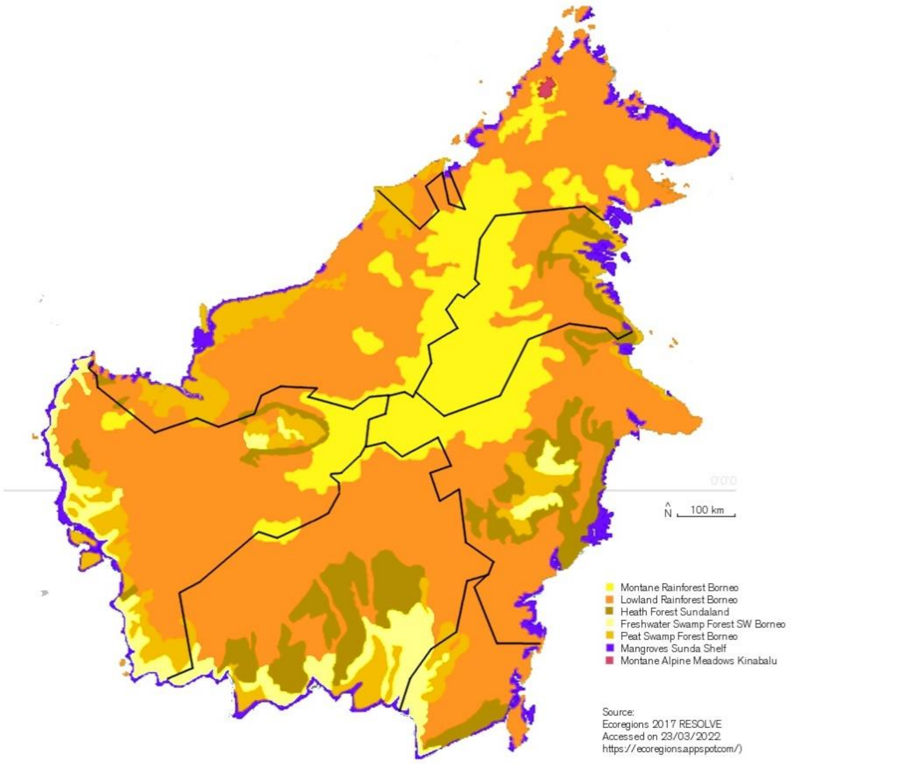

Figure 24. Classified ecoregions on Borneo. The core of Western-Kalimantan is Lowland Rainforest. There are mountains in the east and peatlands in the west along the coast.

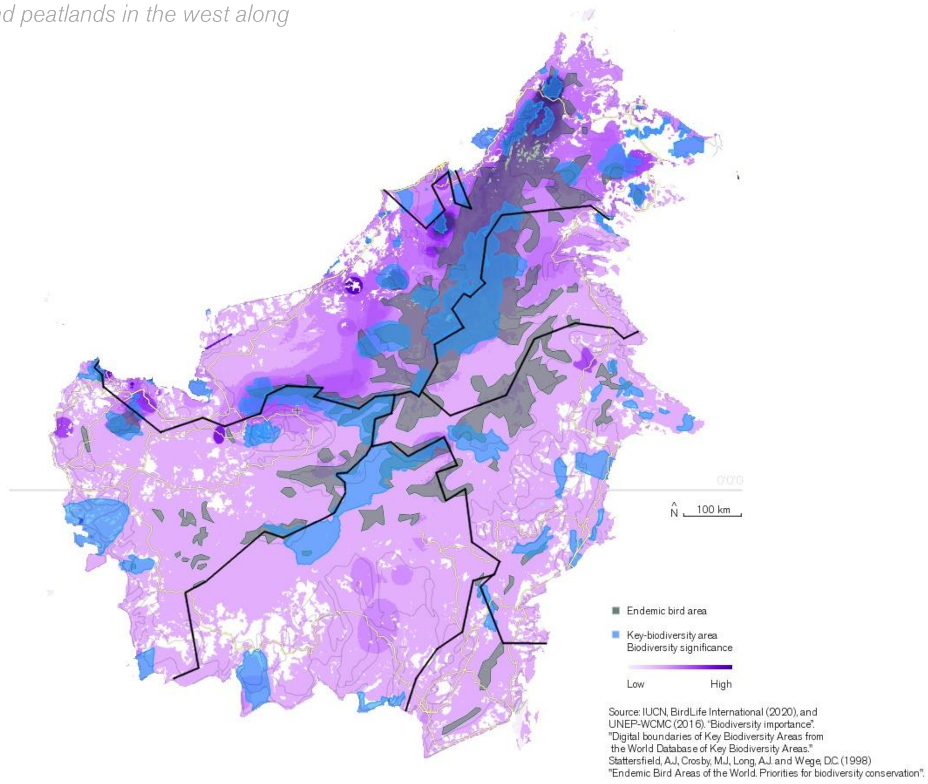

Figure 25. Peat and mountains are deemed the most significant biodiversity 'hotspots'. This could be because here most (primary) forest remains. Malaysian Borneo performs 'higher' than Indonesian Borneo.

4.2 SYNTHESIS

As it stands, large-scale oil palm plantations are monotonous. Such uniform fields stretching over the horizon (with simple shape complexity) reduces juxtaposition and resource availability, especially if palm oil trees are of the same standing age (Azhar, et al., 2015). Landscapes that retain mature stands could benefit biodiversity conservation, since (1) mature oil palms have a more complex habitat structure compared to newly planted stands, (2) undergrowth is able to develop (ground surface is less competed for) and (3) the trees create a more suitable micro-climate (Sheldon, Styring, & Hosner, 2010). To conclude, Steckel et al. (2014) argues that landscape composition (amount and what species) and configuration (spatial resemblance) may even be more important for biodiversity than local land-use intensity.

To design a new generation of regenerative plantations, it is valuable to know in what landscape plantations are currently located in and likely to expand to. This information makes it possible to predict what landscapes have suffered or are going to suffer from palm oil pressure. Biodiversity in these landscapes should be targeted with regenerative design solutions. Spatial factors (derived from earlier shown maps) that influence palm oil expansion have been given a predetermined weight (transparency) and shade (attract or dissuade). The resulting synthesis map (and each variable in a separate layer) awaits below.

Finally, the ecoregions of areas where palm oil expansion is most likely to happen (sufficiently dark on the synthesis map, >50% black) were selected. In conclusion, expansion is most likely to happen in lowland rainforest (but is still possible on peat lands).

Figure 26. Conservation area and 10km vicinity W=1,0

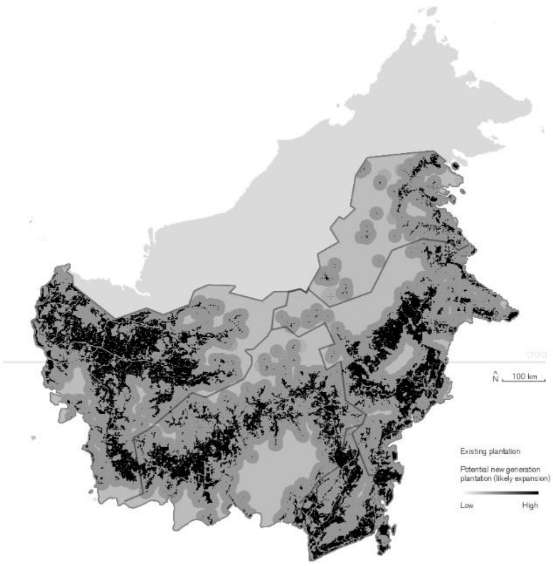

Figure 27. WRI soil suitability and 10km vicinity W=1,0

Figure 28. Moratorium W=0,5

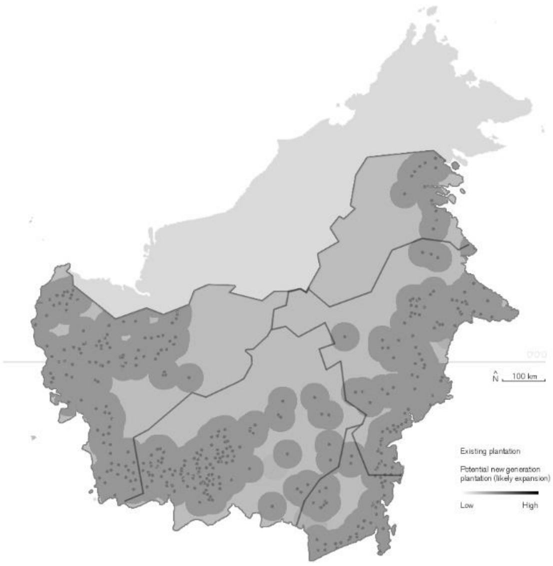

Figure 29. Palm oil mills and 20km vicinity W=0,5

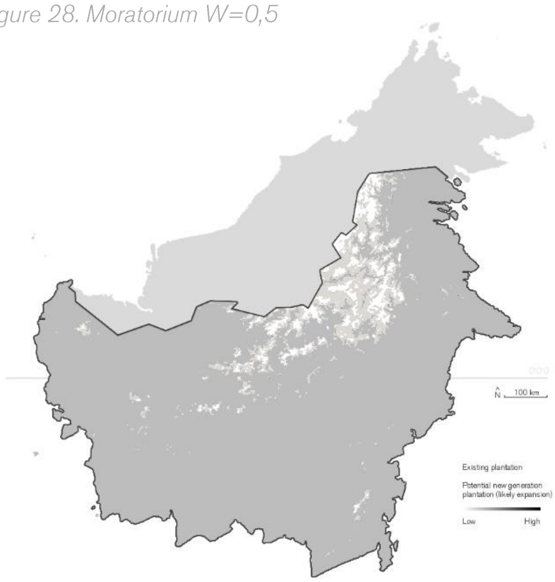

Figure 30. Terrain >1km and >2km W=0,5

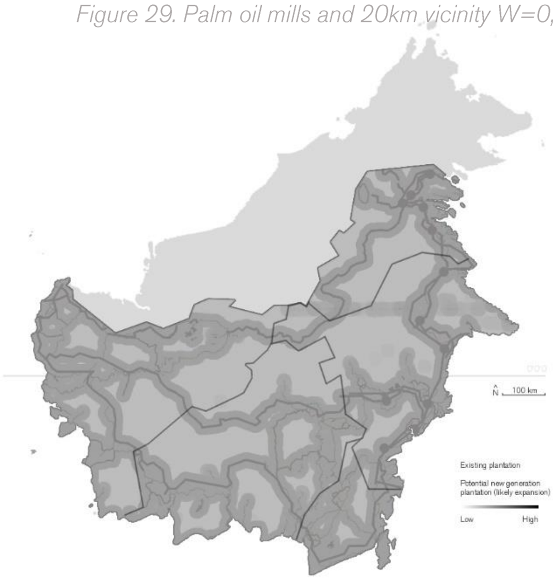

Figure 31. Infrastructure and 10km vicinity W=0,5

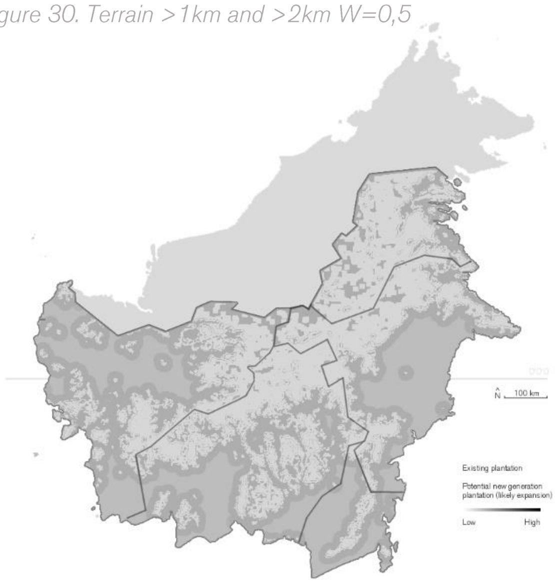

Figure 32. Forested area and 10km vicinity W=0,3

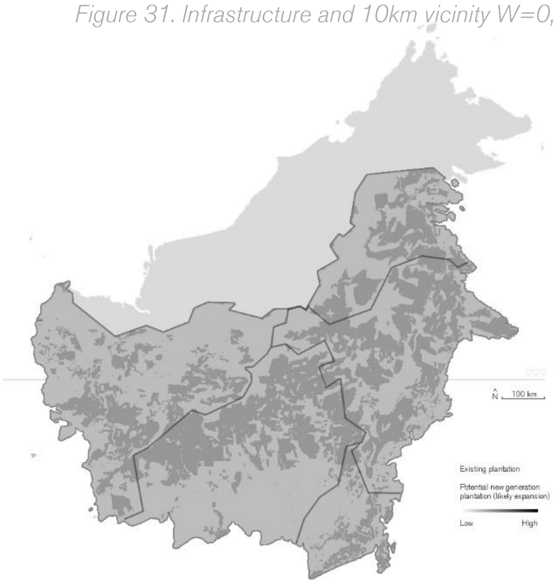

Figure 33. Other concessions W=0,2

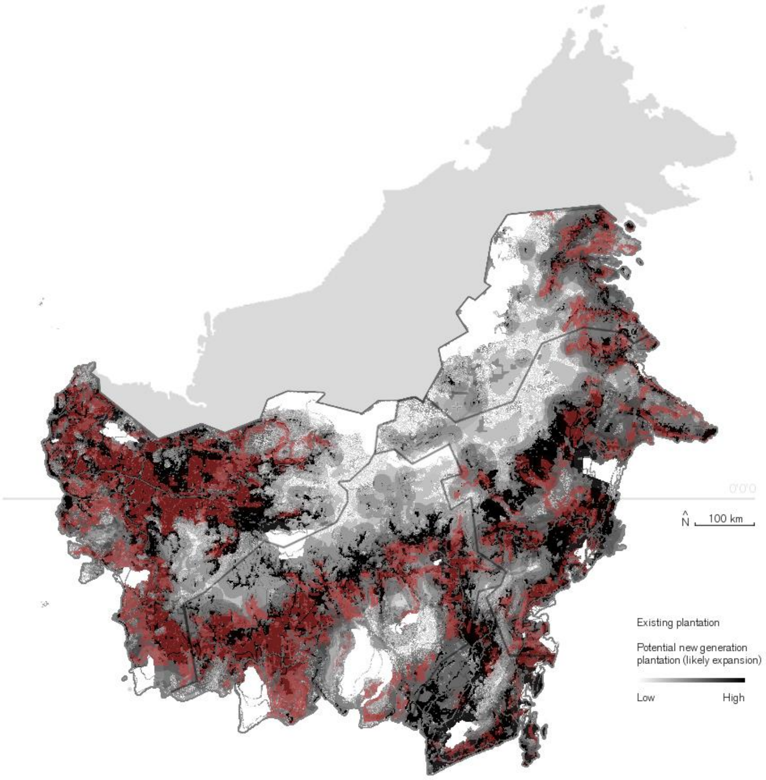

Figure 34. Synthesis (shade) map, projecting where palm oil expansion is most likely in the future. Current concessions are displayed in transparent red.

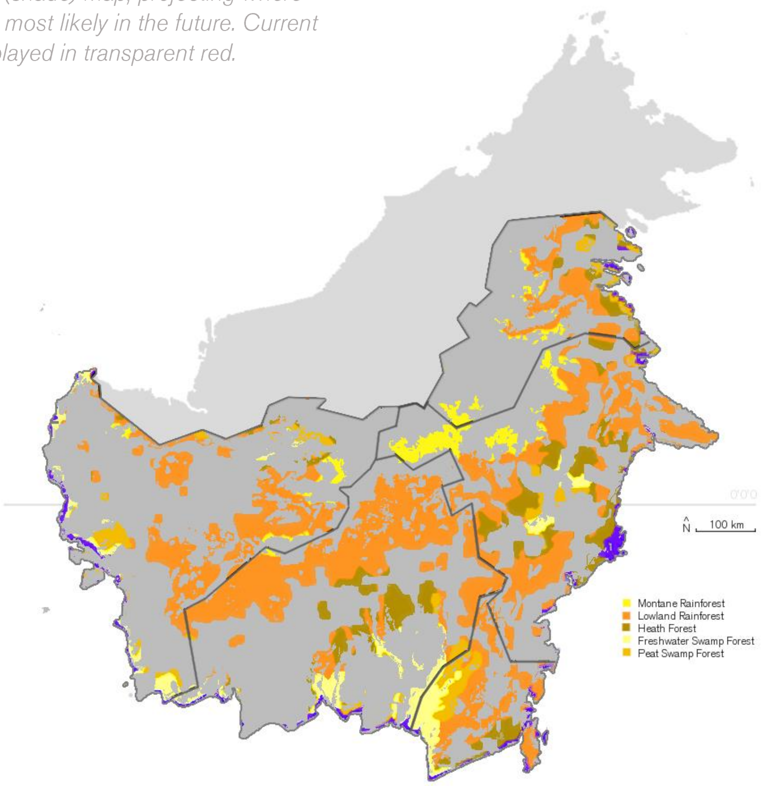

Figure 35. Ecoregions where expansion is most likely to happen. Note that Lowland Rainforest is the 'winner' and expansion on peat is still possible despite regulations.

4.3 TARGET SPECIES

In the timespan of this project it is not possible to figure out the habitat preferences of all native wildlife existing in Kalimantan lowland rainforest. First, a selection of endemic species with highly (%) declining populations due to habitat loss and climate change was made. Eventually four species were chosen: Three birds since they are known to give a good impression to the health of the ecosystem given their wider reach and varied diets (one large fruit eating bird, two singing birds eating mostly insects) and the iconic orangutan (translated man of the forest, who is threatened by the biggest reduction in habitat of all). Populations are all decreasing but remain savable.

1. NAME 2. SCIENTIFIC NAME 3. CLASS 4. ORDER 5. POPULATION 6. IUCN VULNERABILITY STATUS	1. **Helmeted Hornbill** 2. Rhinoplax vigil 3. Aves 4. Bucerotiformes 5. Not quantified (decreasing) 6. **Critically endangered** (2020)	1. **Blue-headed Pitta** 2. Hydrornis baudii 3. Aves 4. Passeriformes 5. 10-20k (decreasing) 6. **Vulnerable** (2016)
7. IDENTIFICATION	7.  Brown and white feathers, red casque and yellow beak. Can grow up to 120 cm. High-pitched "Pooh" and "Poohooh" calls ending in harsh, cackling laugh (Kemp et al. 2014).	7.  Distinctive combination of blue crown and reddish mantle. Can grow up to 20cm. Soft, descending whistle "ppor-wi-ill" (IUCN, 2022).
8. GEOGRAPHIC RANGE	8. 	8. 
9. HABITAT PREFERENCE	9. **Primary** (semi-)evergreen **lowland forest**, up to **1500m**. Prefers rugged terrain and **closed (high) canopy** forests, exceeding **10.000 hectares** (IUCN, 2022). Does occur in 'smaller' conservation areas. Unknown to accept artifical nestboxes (Jain et al. 2018).	9. Locally common (but fragmented) in **primary evergreen lowland forest** up to **600m**. Also occurs in secondary and regenerating selectively logged forest. Sticks to dense cover (IUCN, 2022). Nests in trees, shrubs and on the ground.
10. DIET	10. Feeds on fruiting trees, especially fig. Fledged chicks within the nest demand 900-1900g of fig fruits a day (Kitamura et al. 2011). Seed disperser. Also feeds on small anmimals, such as (stick) insects, squirrels, snakes and other birds.	10. Feasts on caterpillars. earthworms, beetles, ants, grasshoppers, crickets and snails.
11. THREATS	11. Hunting pressure, lowland deforestation, climate change. Suitable habitat expected to decrease by **32%** in 2050 (Singh, 2021).	11. Lowland deforestation, climate change. Suitable habitat expected to decrease by **30%** in 2050 (Singh, 2021).

	Bornean Wren-babbler	Bornean Orangutan
1. NAME	1. **Bornean Wren-babbler**	1. **Bornean Orangutan**
2. SCIENTIFIC NAME	2. Ptilocichla leucogrammica	2. Pongo pygmaeus
3. CLASS	3. Aves	3. Mammalia
4. ORDER	4. Passeriformes	4. Primates
5. POPULATION	5. 10-20k (decreasing)	5. 100k, mean 0.7/ km2 (decreasing rapidly)
6. IUCN VULNERABILITY STATUS	6. **Vulnerable** (2016)	6. **Critically endangered** (2016)

7. IDENTIFICATION

7.


Brown upperparts, white throat. Short tail and long pinkish legs. Can grow up to 15cm. Sings two pure notes "fii-fii" (IUCN, 2022).

7.


Brown/reddish hair. Short legs and long arms as they are arboreal. Although the Bornean orangutang spends more time on the ground than its Sumatrese counterpart.

8. GEOGRAPHIC RANGE

8.


8.


9. HABITAT PREFERENCE

9. **Moist lowland and evergreen forest**, ocassionally peat swamp. Ascends terrain up to 900m. Inhabits dark and shady understory vegetation in pairs (IUCN, 2022).

9. Historically most abundant in **inundated** and semi-inundated **lowland Dipterocarp mosaic forests**, where movement between different habitat types could buffer them against shortages in food availability (IUCN, 2022).

10. DIET

10. Small insects and berries. Hops around the understory, turning over fallen leaves and searching fruit bearing bushes.

10. Primarily gathers wild fruits like lychees, mangosteens, or figs. Slurps water from holes in trees (WWF, 2022). Leaves, bark, flowers and insects are also included in the diet. Fruit bearing trees are widely scattered and only yield enough to feed an indivual.

11. THREATS

11. Lowland deforestation, climate change. Suitable habitat expected to decrease by **66%** in 2050 (Singh, 2021).

11. Hunting, habitat loss, climate change. Models from Struebig et al. (2015) point to a **69-81%** reduction in habitat by 2080 (from 2010) when factoring in both climate change and deforestation projections.

4.4 CONCLUSION

Efforts geared towards improving biodiversity on oil palm plantations hinge on achieving spatial complexity (Koh et al., 2009). Plantations need encouragement to vary in canopy height, canopy cover and understory. Unplanted areas (especially adjacent to forest) can be maximized by maintaining native vegetation (Dislich C, 2017). Species richness takes a heavy blow when converting forest to oil palm, decreasing effectiveness of biological control of pests and diseases. Monocultures provide limited options for animals to gather food and shelter.

In addition to introducing (native) forest and understory, the habitat structure could be made more complex by varying the standing ages of different oil palm 'compartments'. Rather than planting all trees at once, cover crops can be planted in (temporarily) bare compartments. Monoculture drawbacks scale with the size of the plantation, as canopy cover varies widely (20 to 70%) between plantation edge and core. For this reason, regenerative strategies should be targeted at industrial plantations. 85% of plantation surface on Kalimantan is industrial (Gaveau, 2021).

Lowland forest species are most affected by deforestation and climate change. Small birds feed on a diet of insects, which in turns requires understory and flowering vegetation. Orangutans and large birds require loads of fruit, fig seems popular (few remain in the wild or are scattered). Regenerative interventions should first focus on areas of strength (in proximity to pristine nature).

Conclusions from talks with Bob Ursum (head of the botanical garden at TU Delft): On Borneo, the most pristine lowland rainforest can be found in Brunei, where it was conserved throughout history out of religious beliefs. The species richness in this original forest was so high, that every ray of light, every nutrient and even every pollinator was competed for. To overcome the competition, plants specialized themselves to grow taller, to develop more roots or to blossom just before others. This specialization over the ages made original forests rigid (ineffective at re-adapting) to shifts in regime (close environment), consequently returning forest to the original state is a time consuming (count on the scale of centuries) challenge. Long term, preserving will always be cheaper than regenerating.

DESIGN

5.1 CONCEPT AND IMPLEMENTATION

The following chapter is dedicated to establishing spatial guidelines for improving (the environmental and ecological performance of) palm oil plantations, in response of conclusions made in the analysis. These guidelines will eventually be incorporated into the design of a single (pilot) plantation. To ensure the guidelines make it into practice, a plan on how to accelerate the transition of palm oil plantations towards these guidelines is given first (here below).

As it stands, manufacturers and consumers are largely hesitant or don't know how to become carbon neutral. Additional costs are acceptable only up to a certain degree. Hence palm oil manufacturers, such as Kitkat, resort to buying cheap (but ineffective) offsets instead of improving their own supply chain. When buying their tasty goods, you can find 'rainforest alliance' or 'sustainably produced cacao' badges prominent on the label, while a more prominent ingredient is one of the main drivers of rainforest deforestation: Sadly, certification of how the palm oil was produced is missing. This might be because individual plantation traceability is difficult to implement as many plantations bring their palm oil to a single mill where it gets mixed up. Another reason could be that only a fraction of current plantations (13%) are within the RSPO program.

To get RSPO certification, a specialist needs to physically visit the plantation, check whether there are 'high conservation areas' within the plantation, and then derive a specific plan on how to deal with them (no standardization means plantation holders do not know what interventions to expect beforehand, there is little transmission of knowledge and the title of RSPO-certified is not always as hard to obtain or valuable, as there is no spatial standard). Every year, the specialist revisits, already if no changes were observable the certification remains in place. If there are no conservation areas within the plantation (or if they have already been cleared) it is unclear how RSPO-certified plantations distinguish themselves from their non-certified counterparts. The analysis, at least concluded that there was no significant difference in their performance on biodiversity. As more area gets claimed by oil palm monocultures, adapting current plantations becomes the larger (and more rewarding) challenge. Regenerative strategies hinge on achieving spatial complexity. It is the goal of this design chapter to provide a standard (guideline) for achieving spatial complexity within industrial oil palm plantations. These spatial guidelines go beyond RSPO certification and are from here on referred to as RSPO+.

On the next page, a timeline portrays how the market share of RSPO-certified plantations grew in the last 20 years to 13%. If this trend continuous in the autonomous scenario, it is expected that around half the plantations will be RSPO-certified by 2080. In consequent timelines, the expected market shares of non-RSPO, RSPO and RSPO+ plantations are depicted together with (an action plan:) policy incentives to accelerate the transition. To accelerate change, soft incentives should initially be prioritized rather than waiting for the government to undertake (hard) regulating action. The RSPO should start asap with establishing pilot RSPO+ plantations, since establishing a spatial standard takes time (for potential iterations) and is the prerequisite for a (more ambitious) certification scheme.

Proposed (spatial guidelines for) RSPO+ certification 'regeneratively produced palm oil' allows consumers to choose products based on whether they want to offset their environmental impact. Manufacturers will respond to demand and can market their sustainable efforts. Then, when the RSPO+ concept has 'proven' itself with time, governance can make certification obligatory. Funds could be gained from the REDD+ program, biodiversity funds from investment banks, voluntary manufacturers, but also plantation holders themselves: Possibly by charging (10%) more land rent for the most competitive soil (black areas in the synthesis map) when not in line with the RSPO+ standard, leading to eventually discontinuing non-certified concessions.

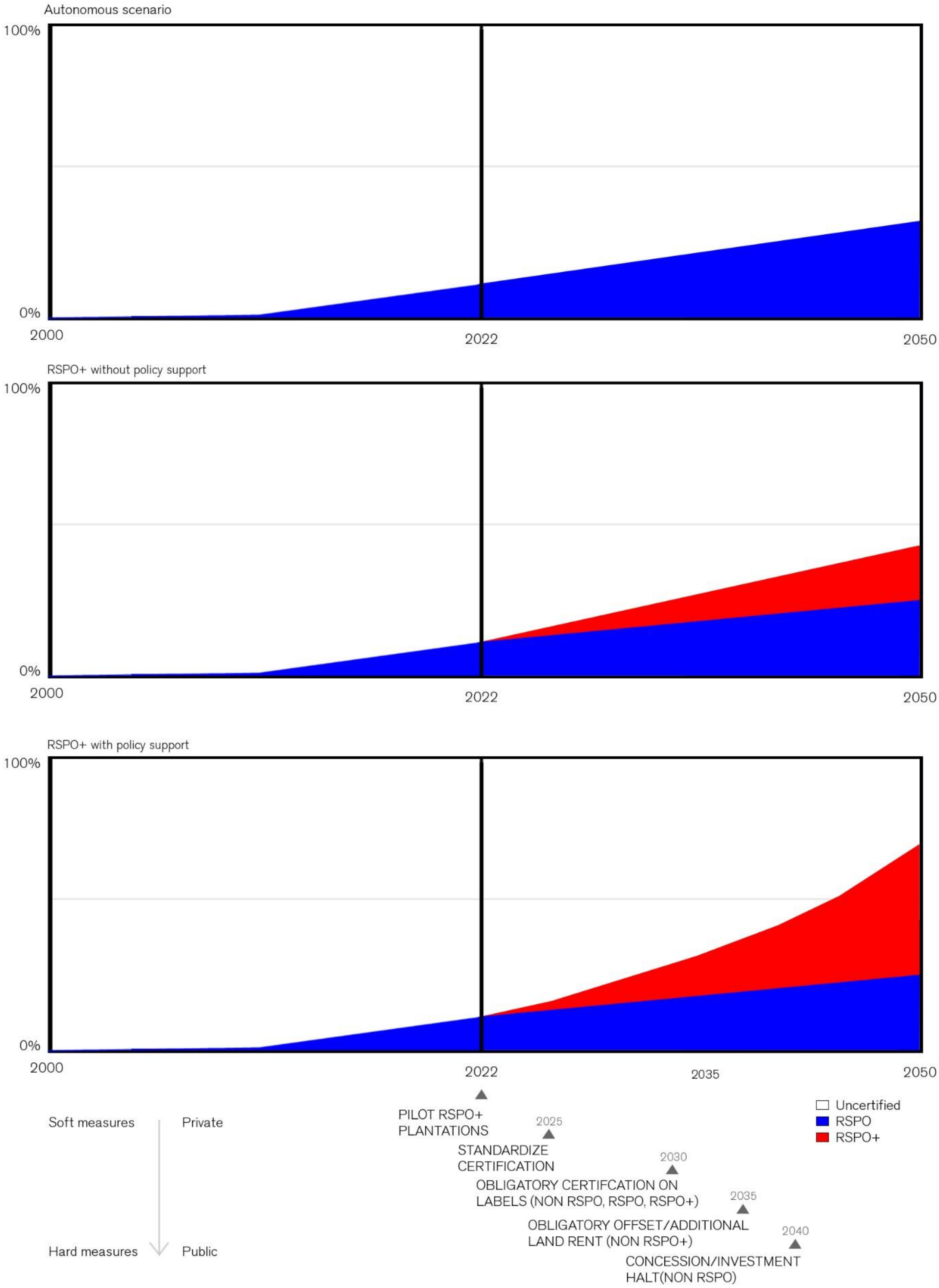

Figure 37. Market shares in the autonomous scenario, and while incorporating RSPO+ (with and without supportive policies).

5.2 GENERAL DIAGRAMS

Chapters 5.2 to 5.5 elaborate how to achieve spatial complexity for industrial palm oil plantations on the microscale using (top view) diagrams. These chapters can be classified into core interventions (not specific to a geological context and thus are applicable in general) and measures dealing with commonly faced irregularities (e.g. rivers, interior forest patches). Being modular, the building blocks can be 'linked up' to form the blueprint of a whole plantation. As such, principle diagrams can be applied to industrial plantations of different shapes, scales and contexts. An example integration of the different microscale guidelines into a redesign of a specific (pilot) plantation is given in 5.8.

Plantations established in the 1970's usually follow a regular (square) grid with oil palms planted at 8m from each other. More recently established plantations are often interchained (triangular grid). Because this modern grid is maximized for intensity (150 palms/ha), the space in-between harvest circles cannot be efficiently used for intercropping: linear alleys are not possible as can be seen in the figure below.

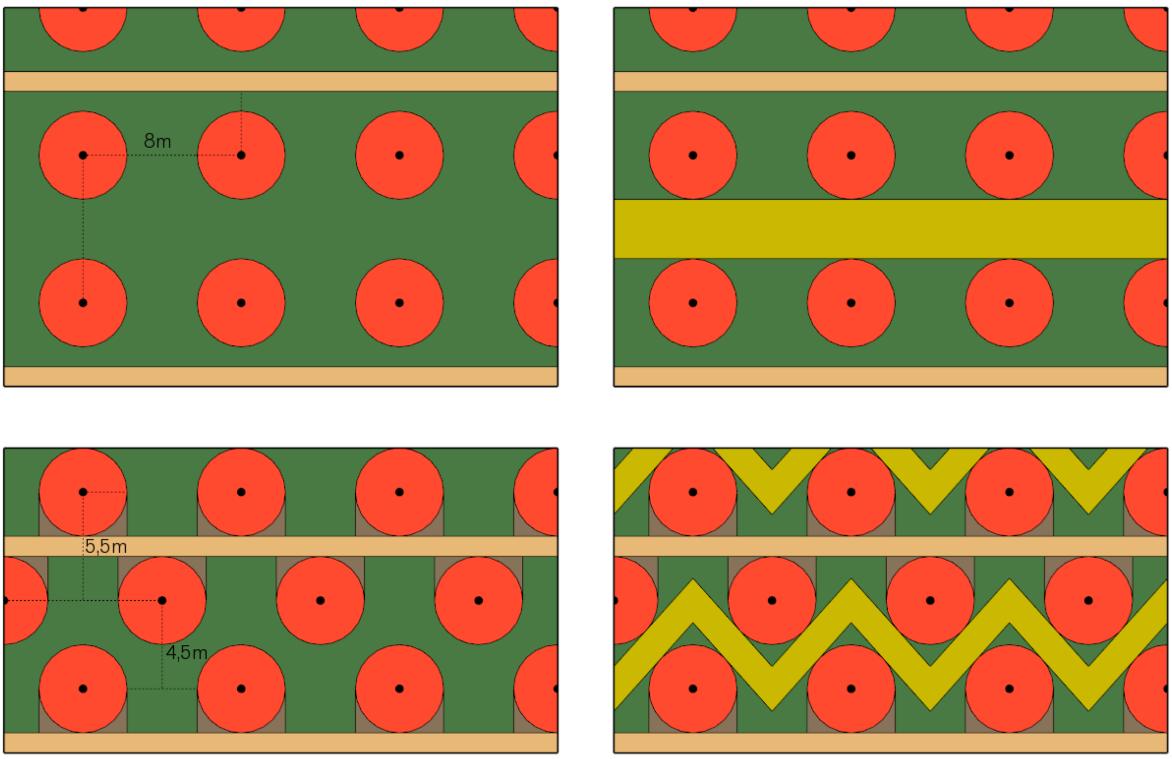

Figure 38. Core diagrams of existing plantations. Square grid on top, interlocked bottom. Note that linear intercropping is not possible in the (intensely) interlocked plantation.

As the default spacing pattern, a triangular grid of 9x9x9 m (150 palms per hectare) is proposed. This is essentially a combination of the patterns above and offers the best of both worlds: By enlarging the space 'behind' oil palms rows (where no pathway is) a 4,5m wide row becomes available for intercropping (ETA and TBI, 2021). The interlocked configuration is maintained as this allows for more efficient use of space (soil and light). Additionally, this provides a more suitable microclimate with less wind erosion (compared to the square grid).

Intercropping is especially beneficially in the first 5 years of plantation establishment, where it is proven not to interfere with the growth of palm oil (ETA and TBI, 2021). Intercropping in mature plantations is also possible, but require shade-tolerant crops. Alternatively, it is possible to prune the oil palms to let more daylight in, but currently it remains unclear whether this trade-off is worth it (palm oil yield will likely decrease). Intercropping provides extra income, lowers dependency (on a single crop) and reduces costs for weed management, while balancing nutrient cycles: Increased microbial abundance leads to increases in nitrogen, carbon and phosphorus cycling. Spatial requirements of different intercropping crops are displayed in figure 45, the species in bold are tolerant to shade and can persist in mature plantations.

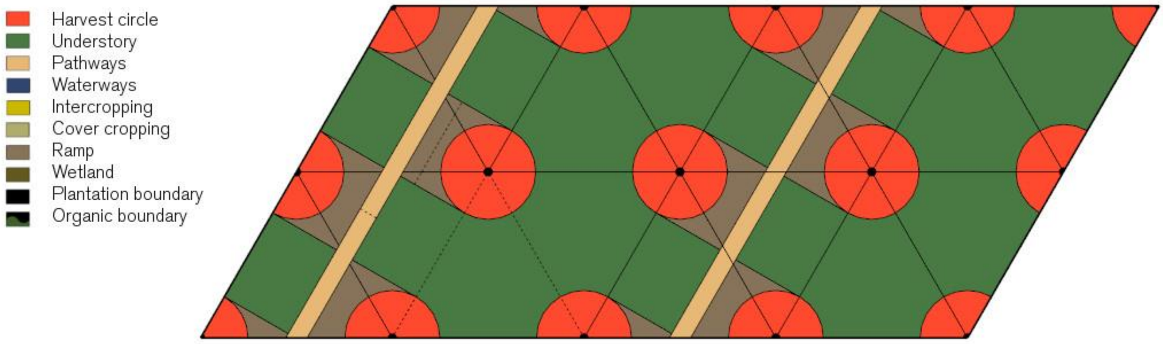

Figure 39. The 9x9x9m grid. Regular spacing is the easiest to establish and maintain. Of course, using this grid alone will achieve diversification.

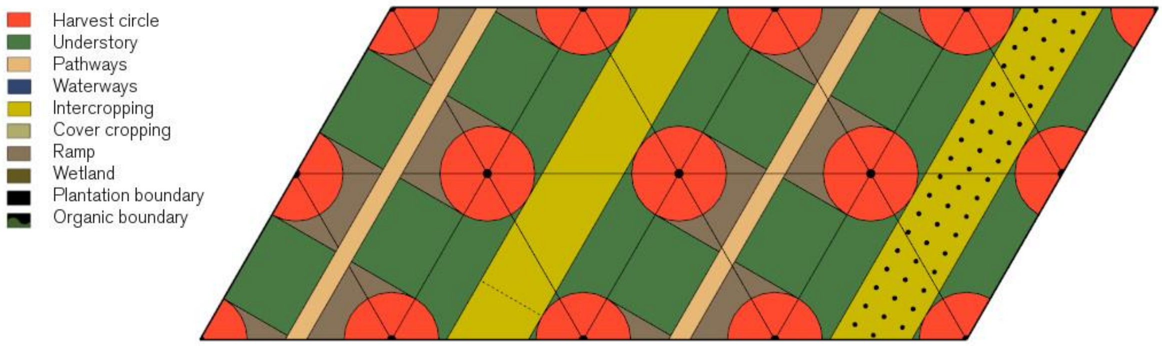

Figure 40. Proposed scheme for intercropping. To think about: at what orientation would the alleys receive most sunlight coming in?

Existing drainage ditches have the potential to become biodiversity hotspots, as small animals and birds like to gather food around water. The vegetation around these ditches could be dense, since not much human activity (movement) is expected here. These waterways could then be used to reconnect fragmented habitats. Inspiration is taken from the Dutch Elzensingel, what native vegetation could fulfil the same role in Kalimantan remains unclear at this point. The vegetation should be able to grow (and reinforce) on shores and in semi-inundated spots, grows not taller than 8m (subtree), not pose too much competition for nutrients with palm oil and tolerate a wide variety of understory.

Since mature and young palm oil plantations vary in canopy height, canopy cover (and thus understory), spatial complexity can be achieved by planting the oil palms in stages. In case of adapting an existing plantation, trees can be logged in stages and leaving the unplanted areas bare would be a waste. Hence, cover cropping is proposed (planting an alternative, fast growing crop in between harvest cycles).

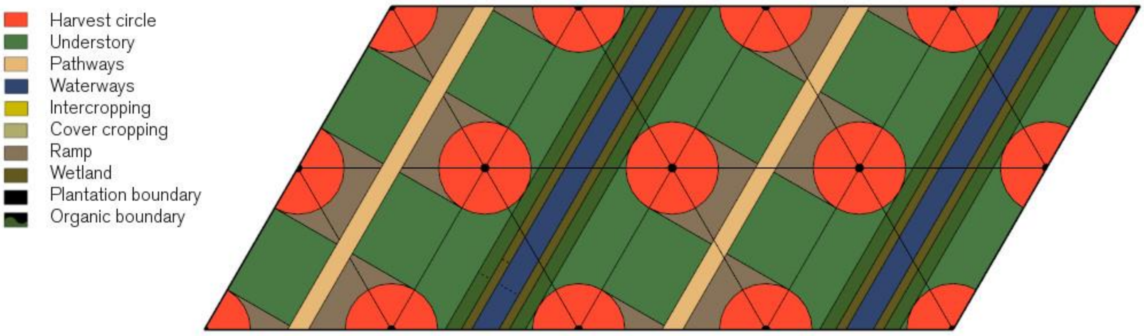

Figure 41. Enhanced waterways (instead of using up the intercropping space, pathways could also be sacrificed but this is optional).

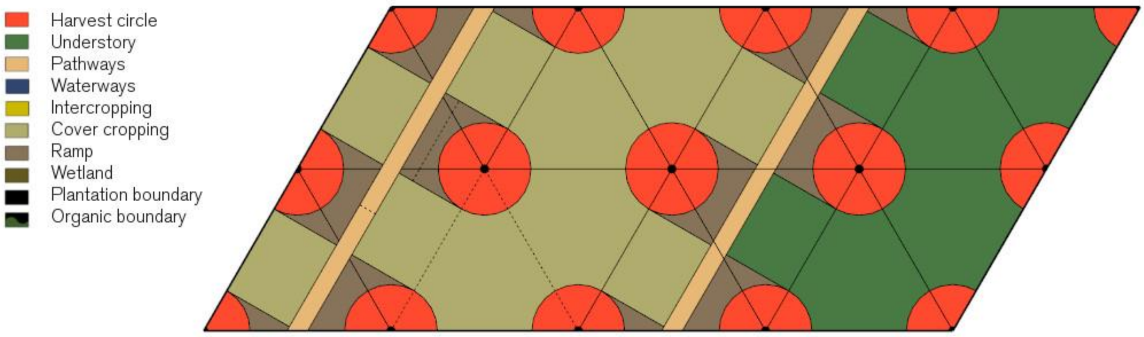

Figure 42. Different oil palm ages in different compartments with cover cropping

Figure 43. Intercropping with banana in Malaysia. © Maja Slingerland

Figure 44. Intercropping with rice does not require alleys. In the bottom left a drainage ditch can be seen. © Thijs Pasmans

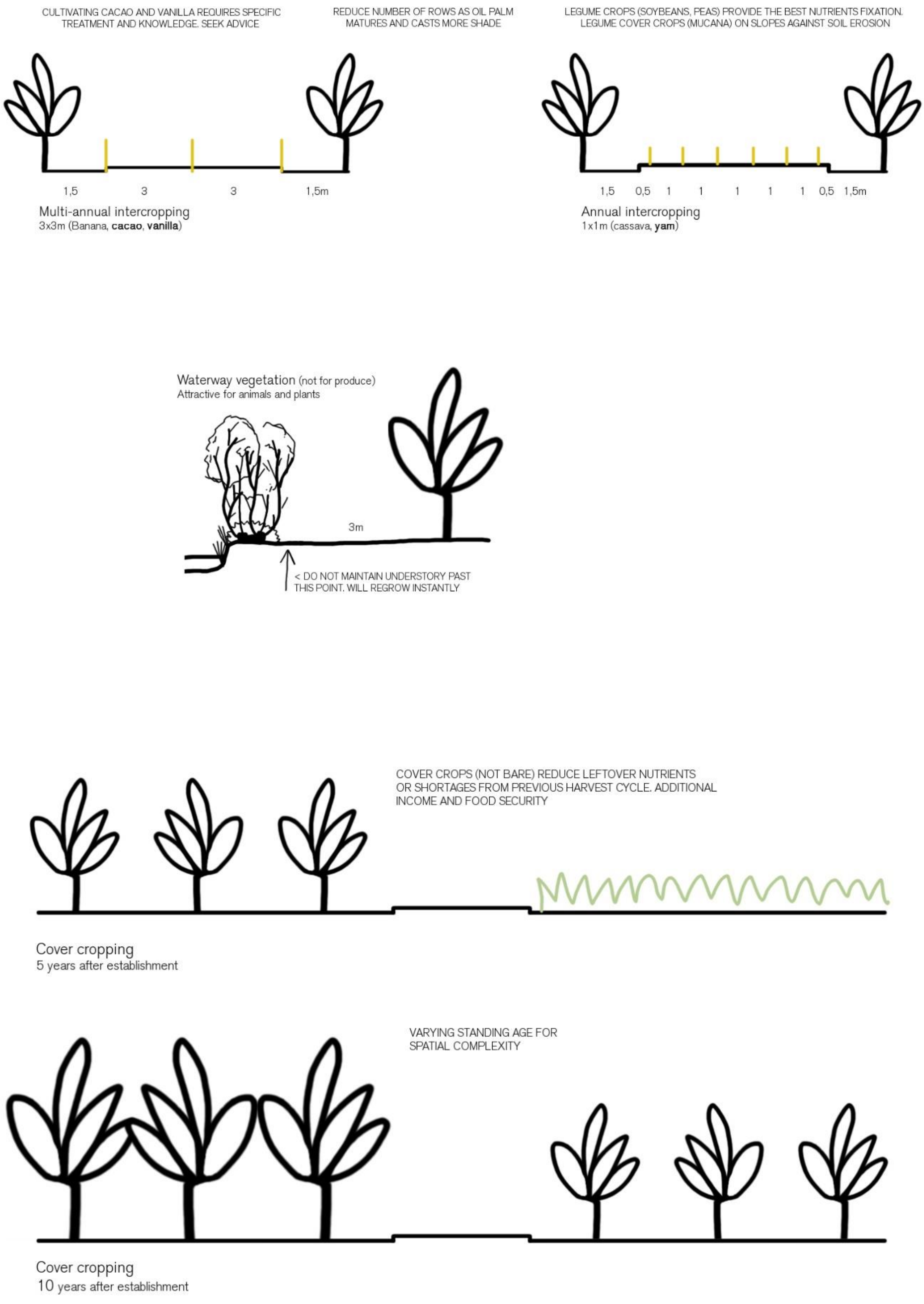

Figure 45. Conceptual sections for intercropping, ditch planting and cover cropping

Around the plantation, a strip up to 20m wide is reserved to plant native trees. It is primarily done to conserve plantation moisture and to protect against wind erosion, aspects of great value to young plantations. Boundary planting marks out land ownership, reducing conflicts over property rights and prevents illegal expansion. For these reasons, the boundary should be dense and multi-layered (see 48 on the next page). Species mixture improves biodiversity and ecosystem functioning. After the full harvest cycle, the core should be logged but all regenerated boundaries should remain.

Wetlands buffer strips along rivers and sedimentation ponds slow down water yield and allow purification (of drainage water) by sedimentation and plant uptake. Reducing nutrient losses to surface water considerably (ICPDR, 2021). Sedimentation reservoirs are valuable to improve water quality and combat eutrophication. In periods of drought they can act as water reservoirs, improving the landscape water budget and stabilizing yields in agriculture.

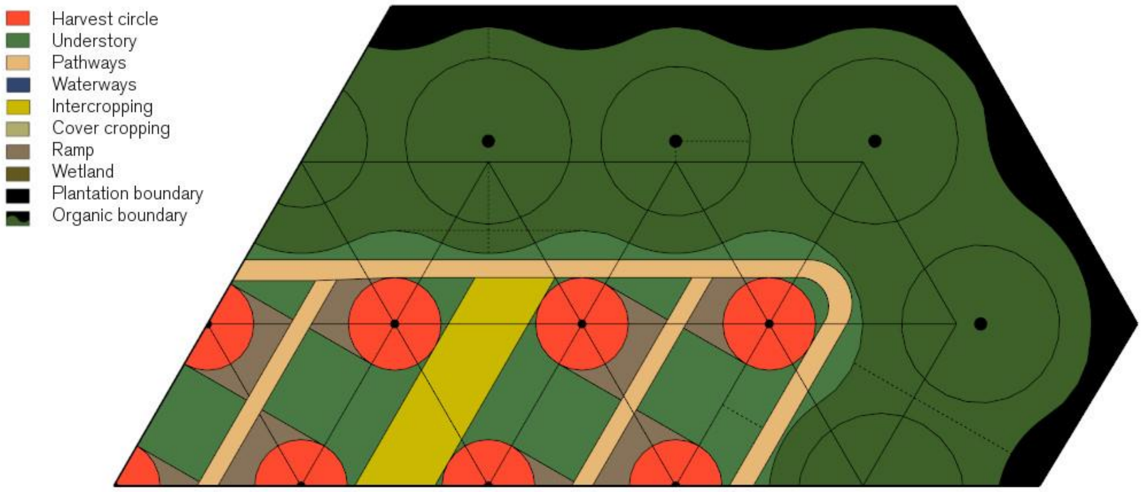

Figure 46. Boundary planting

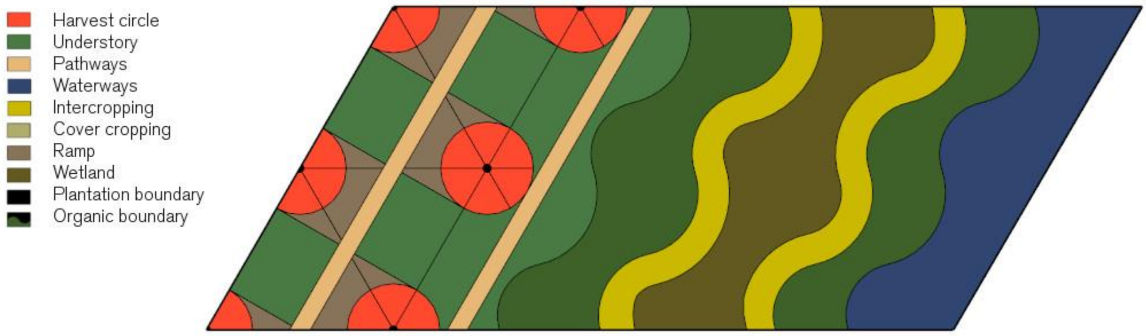

Figure 47. Riparian buffer zones

Figure 48. Multi-layered layers in the boundary. To stimulate small birds/insects the share of flowering trees should be raised. Fruiting trees (namely fig) provide food for large birds and orangutans.

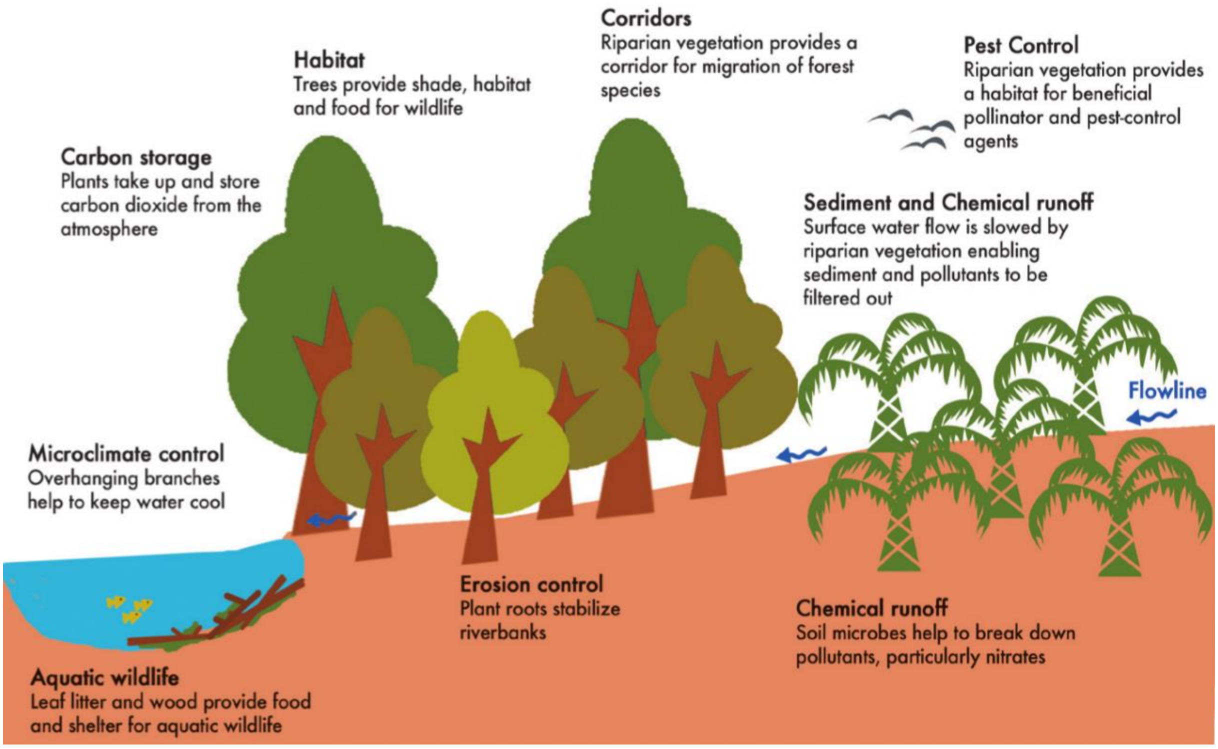

Figure 49. Conceptual section with the benefits of riparian buffers according to the (RSPO, 2018)

5.5 IRREGULARITIES

A logical drawback of using a regular grid for palm oil plantations is that any irregularities (interior forest patches or terrain) are inefficient and are usually not tolerated. Rigidly sticking to a grid often means levelling the playing field altogether. For flexibility reasons, the grid can be locally widened (by a X-fold of 1,5m) and filled with intercropping rows.

The widened space for intercropping means enough daylight will come in (despite oil palm age and canopy cover) to facilitate permanent use. Higher value species, such as black pepper becomes available. Even if nutrients are 'taken' from surrounding oil palm, the price/of black pepper is significantly higher than that of palm oil, but growth rates are slow (ETA and TBI, 2021). Black pepper requires a spacing of 2,5m to each other and 5m to oil palm.

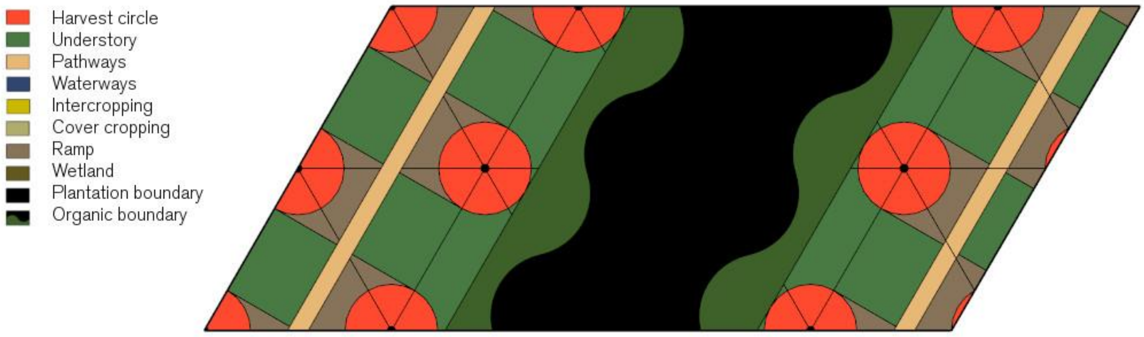

Figure 50. Forest patch/migratory corridor

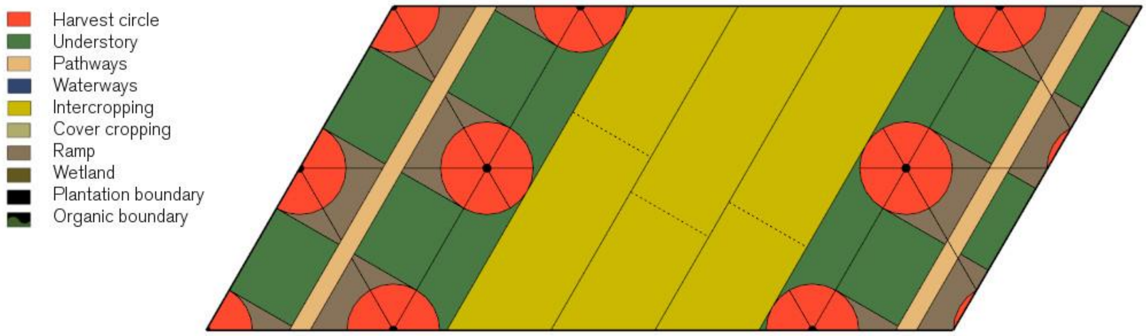

Figure 52. Three intercropping 'avenues' of 4,5m to alleviate the irregularity.

Figure 53. Levelling the playing field, now the plantation grid awaits. © H Dragon

Figure 54. Double row intercropping in Malaysia. Cassava on the left and black pepper on the right. © Maja Slingerland

5.6 PILOT PLANTATION: SITE SELECTION

The microscale diagrams will now be ‘assembled’ and put into practice, using them as building blocks to create an integrated mesoscale redesign of an existing uncertified plantation. The spatial vision is geo-specific and cannot be replicated 1-on-1, but provides an example of how combined measures affect the spatial complexity of an oil palm plantation.

In choosing what plantation (and where) to redesign, multiple factors played a part. First off, the plantation should be in-between intensive palm oil concession area (lowland) and the interior (brush lands) where nature remains (as envisioned in the figure below). The reasoning behind choosing a plantation in this transition zone is that measures to limit the biodiversity and environmental impact are most valuable here (close to animals and people).

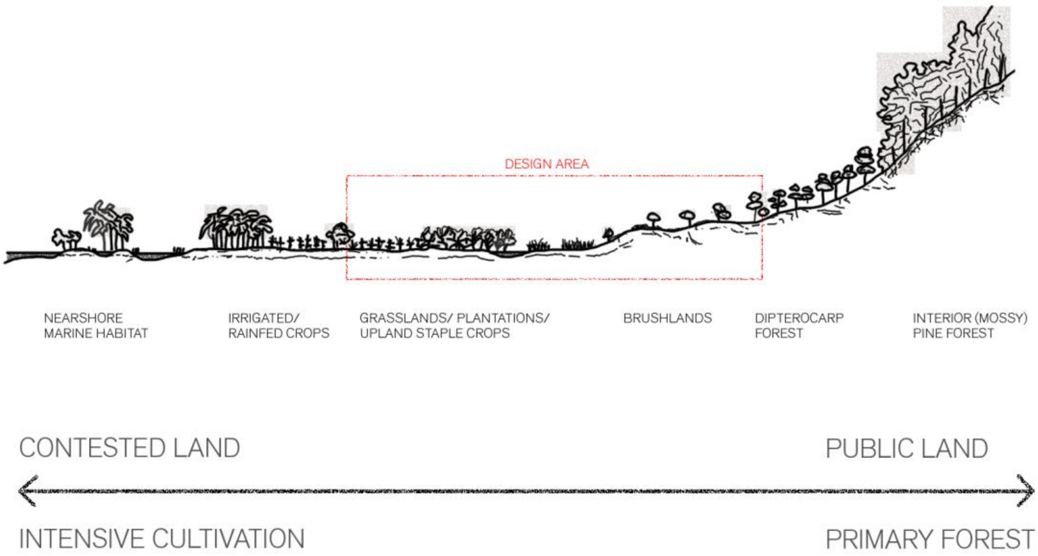

Figure 55. Cross section of Kalimantan with highlighted intervention area.

Figure 56. Melawi, a regency in Western-Kalimantan province has the elements searched for. In the Northwest, the lowland is already dominated by palm oil, but mass expansion is still possible and expected here. Additionally, a lot of ‘conservable’ interior nature remains in the South-east. In the figure on the right, this regency is highlighted in green.

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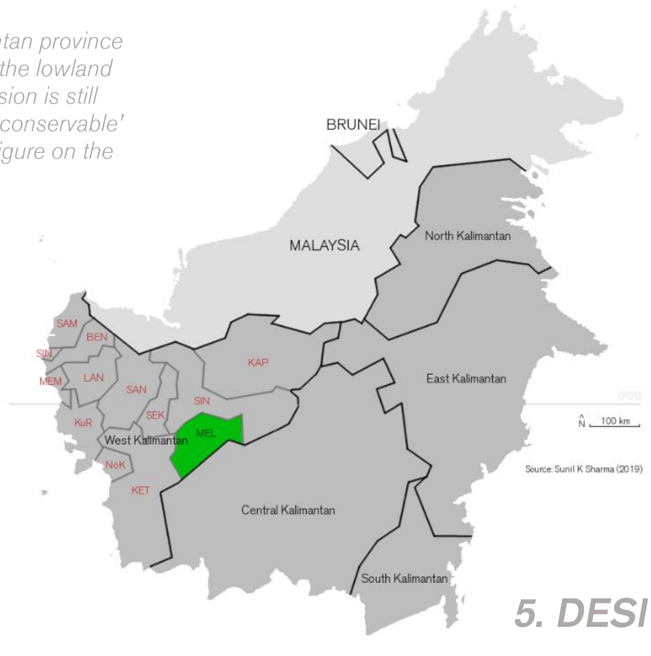
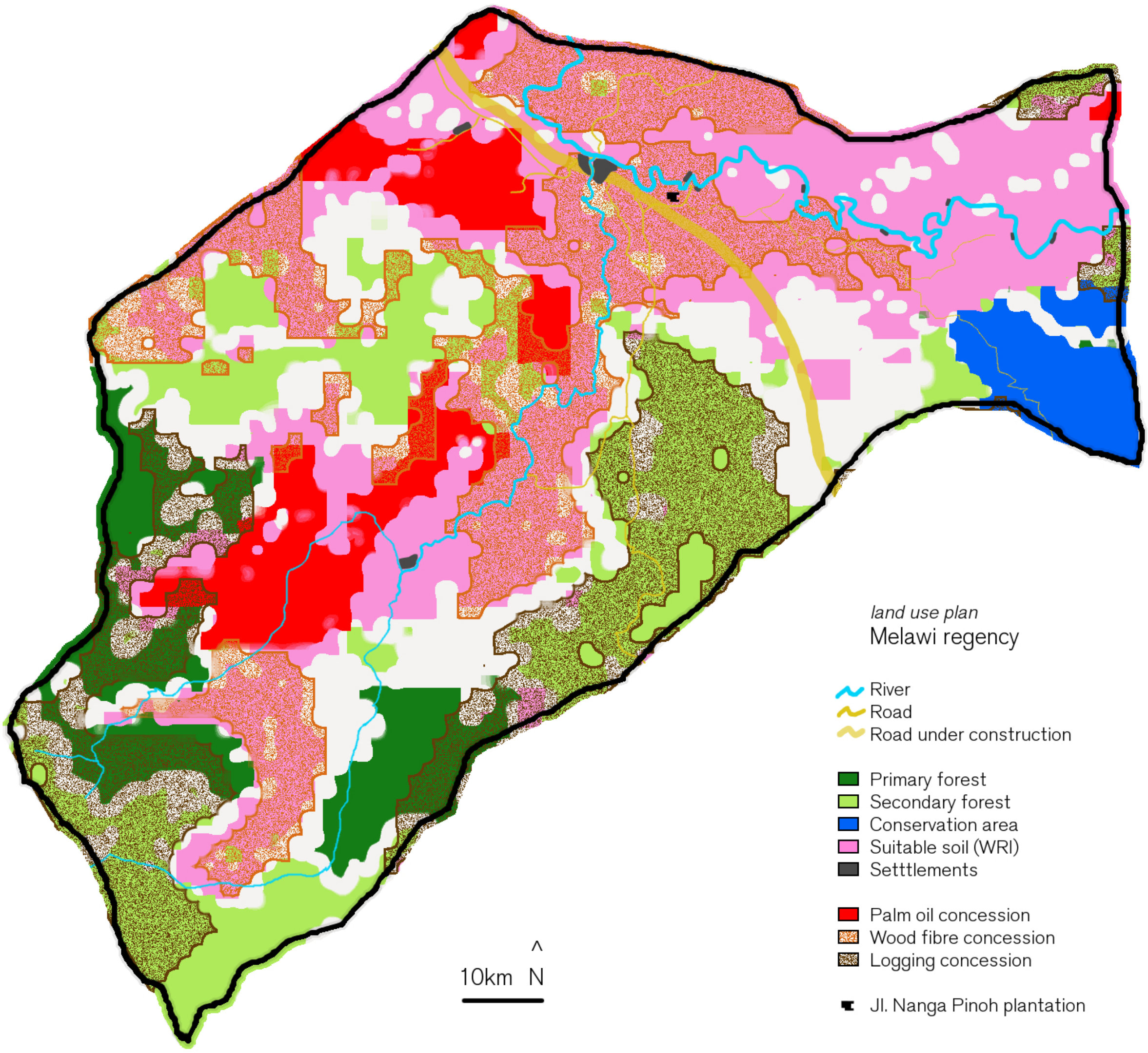


5.7 PILOT PLANTATION: MACRO AND MESO

Within the Melawi regency, a single plantation needs to be chosen. For this reason, a land use plan was made for the region, merging (detailed, 'zoomed in') relevant layers from the analysis part (see legend). From this map, it is important to note a few conclusions: Not roads, but rivers are historically the most important infrastructure. Settlements are located along the river (often not accessible by road), with the largest settlements on intersections of rivers. Palm oil concessions are found close to these human settlements, within 'suitable soil' selected by the WRI. The soil deemed most suitable for palm oil cultivation (in pink) can be found along rivers. As to why this is the case, it is assumed that the river (positively) influenced soil fertility and type. Additionally, the land near the river is often flat (valley), which could also help explain the apparent connection.

Furthermore, it is striking that even this close to the interior, primary and secondary forest are relatively unprotected and under threat of logging concessions. The small forest reserve classified as conservation area (blue in the east) has a road going through and is surrounded by logging concession. Currently it is unclear how conservation area is (spatially) protected or regulated.



Much of the land where palm oil expansion is likely (and happened when comparing with satellite images) is classified as 'wood fibre concession'. Wood fibre (fast growing trees to produce paper and pulp) is a relatively small industry compared to palm oil, so logically you would not expect so much 'competitive' land to be sacrificed for it. Perhaps the wood fibre and logging concessions partly serve to indirectly facilitate oil palm expansion, by degrading (clearing) the forest. This way, the environmental impact of palm oil expansion is marginalized or 'hidden'.

Approximately 10km east of the largest settlement (Sidomulyo), a viable candidate plantation for implementation of proposed measures was found. This plantation (from here on referred to as Jl. Nangah Pinoh) is typical in grid and establishment, is enclosed by a major river in the north, includes forest patches and drainage ditches in former peatland. The plantation is established outside of area classified as palm oil concession, but within wood fibre concession and 'suitable soil'. The size (around a square km) is relatively small for an industrial plantation, but this is a viable (readable and workable) scale to show all proposed measures. In addition, satellite images of this plantation are in high resolution (see figure below, not so common for the interior of Kalimantan).

Figure 58. Satellite view of the selected plantation: Jl. Nanga Pinoh. The main pathways of the plantation are accentuated in brown and the edges in

The next page is dedicated to showing how this plantation was spatially established and how it expanded over time. When oil palms reach an age of 25-30 years old, they are usually logged (all at once because efficiency) while still producing fruit, since they become too tall to harvest (by hand and tools). Instead of starting a new harvest cycle using the same (intensive) monoculture grid, this is the optimal moment to implement proposed spatial changes. The resulting image (and sequence) of these interventions follows in the beyond RSPO spatial vision.

5.8 (APPLIED) TYPICAL SECTIONS AND OVERVIEW

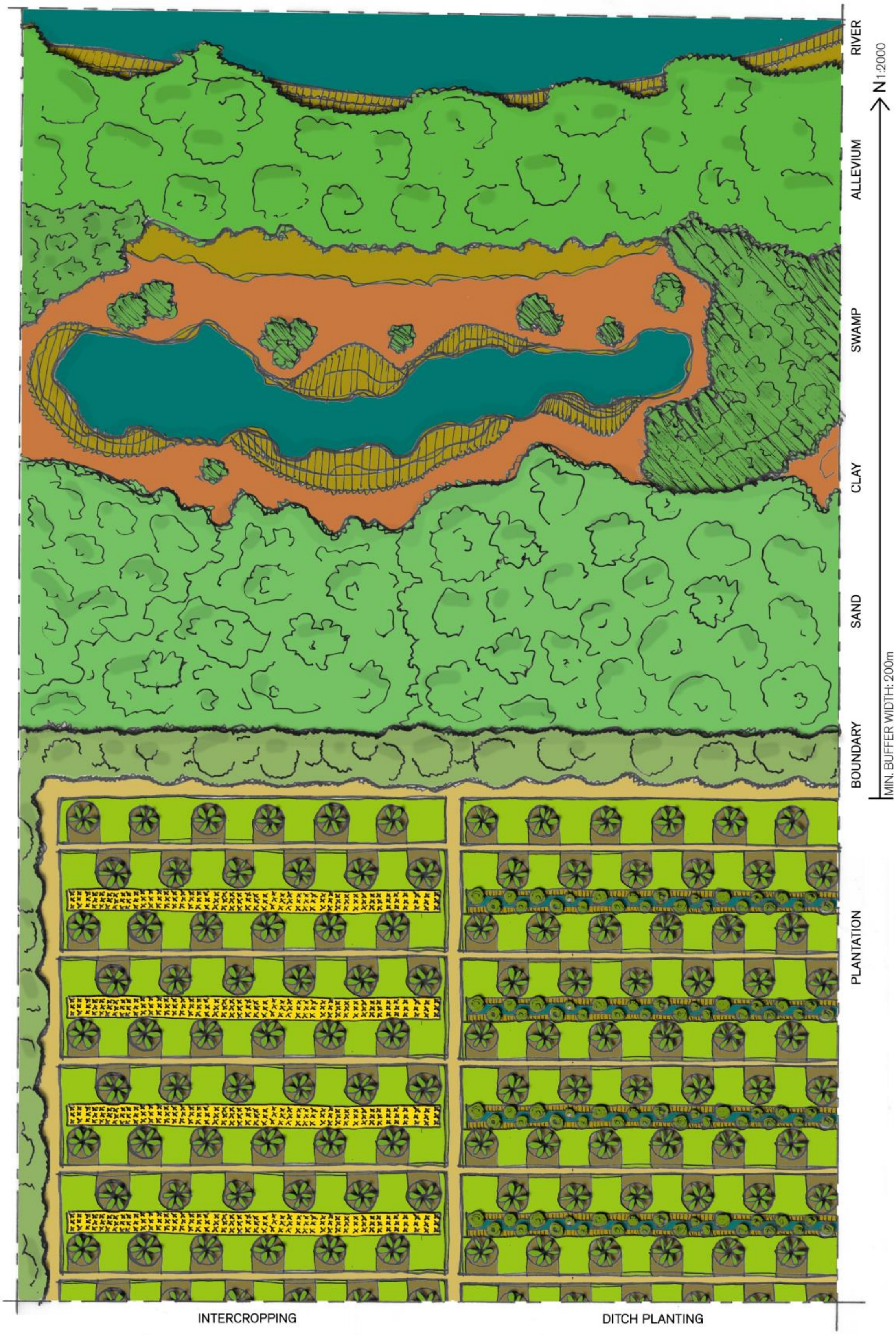


Figure 59. Typical (zoomed in) overview of the pilot plantation at the river edge, including a variety of proposed spatial measures. Original scale is 1:2000, as oil palms are really 8m apart.

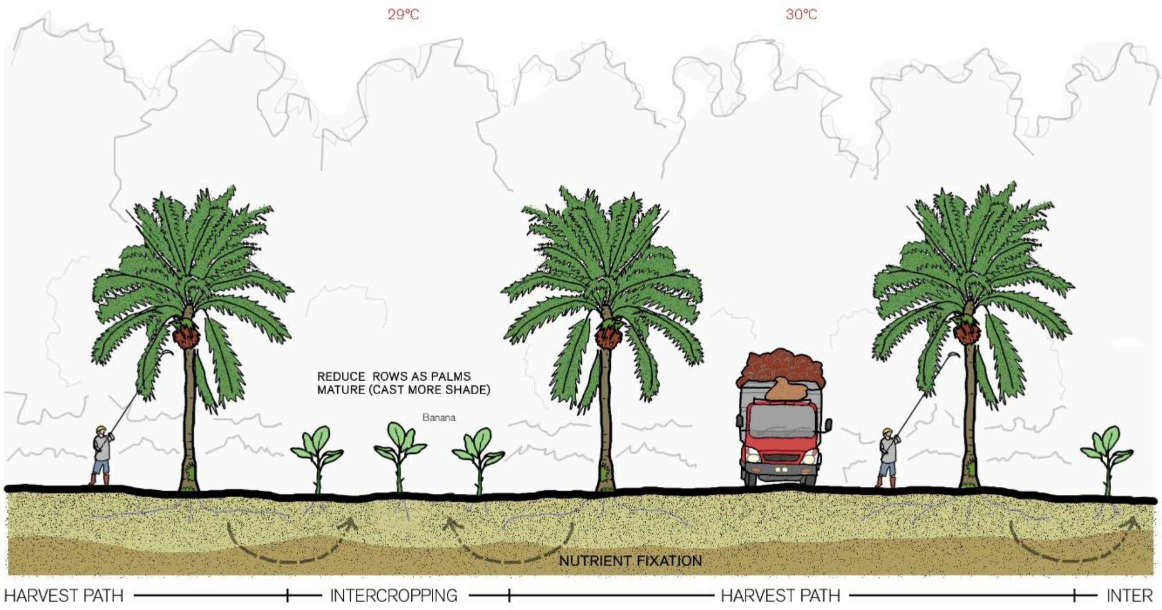


Figure 60. Typical section of intercropping (banana) within the plantation. Alternative 3-meter-apart row crops are cacao and vanilla, but cultivating these requires more expertise. Nutrients fixation denotes the absorption of nutrients by the secondary crop, preventing fertilizer overshoot. The scale is 1:200.

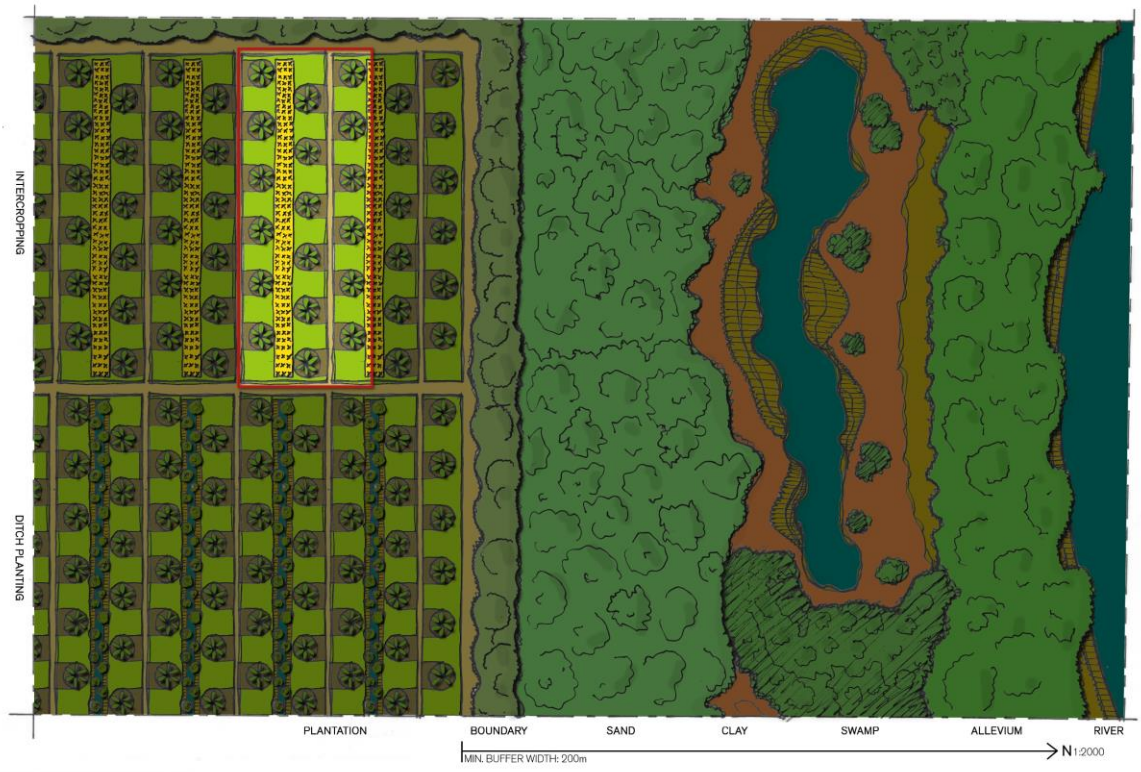


Figure 61. Spotlight: Location (top view) of the section above within the plantation.

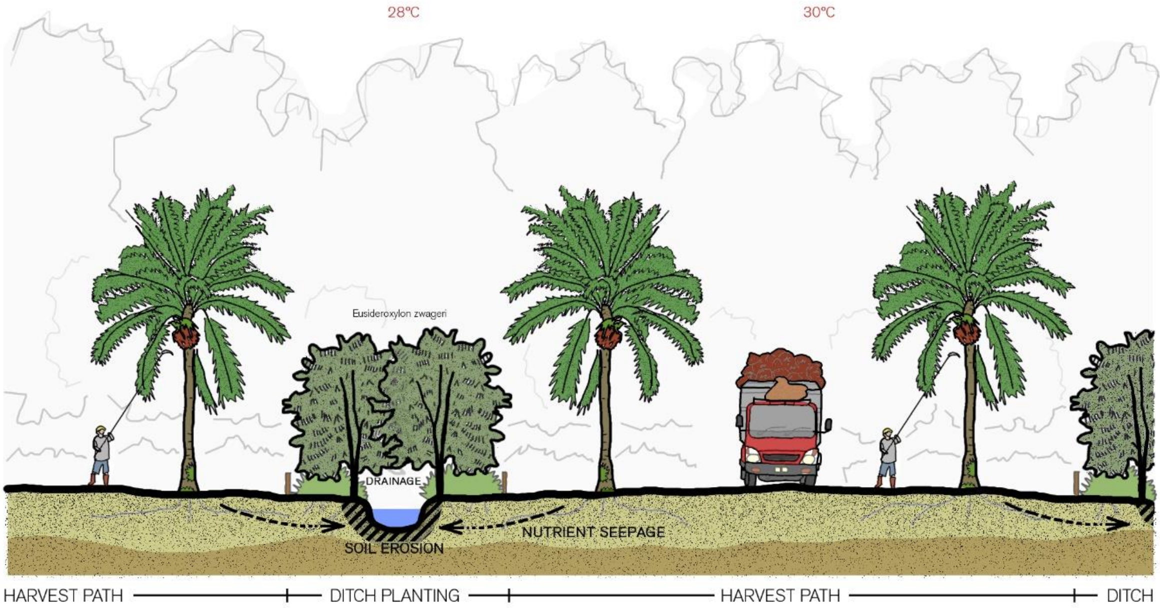


Figure 62. Typical section showcasing a potential way of ditch planting. The drainage ditches are strategic locations to intervene on, as from here soil and many nutrients seeps away with the water into the exterior. Multi-stemmed trees have the priority as they are known for their better cooling, and 'reinforcing the soil with roots' potential.

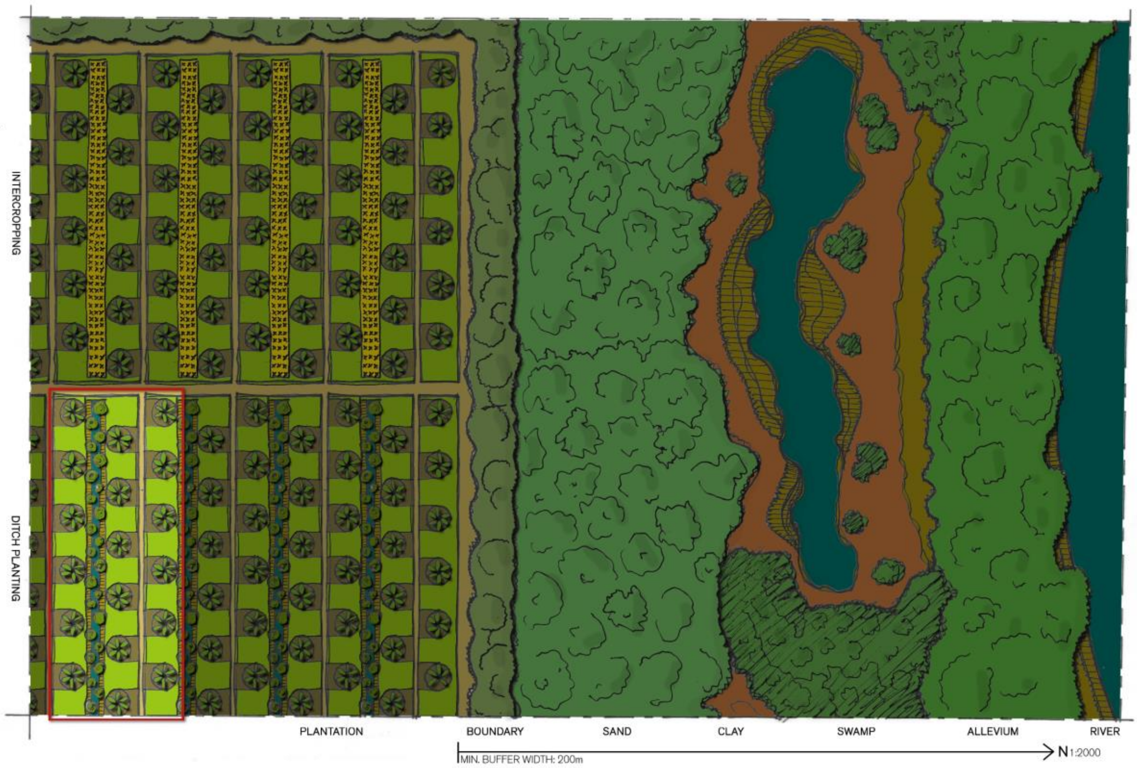


Figure 63. Spotlight: Location (top view) of the section above within the plantation.

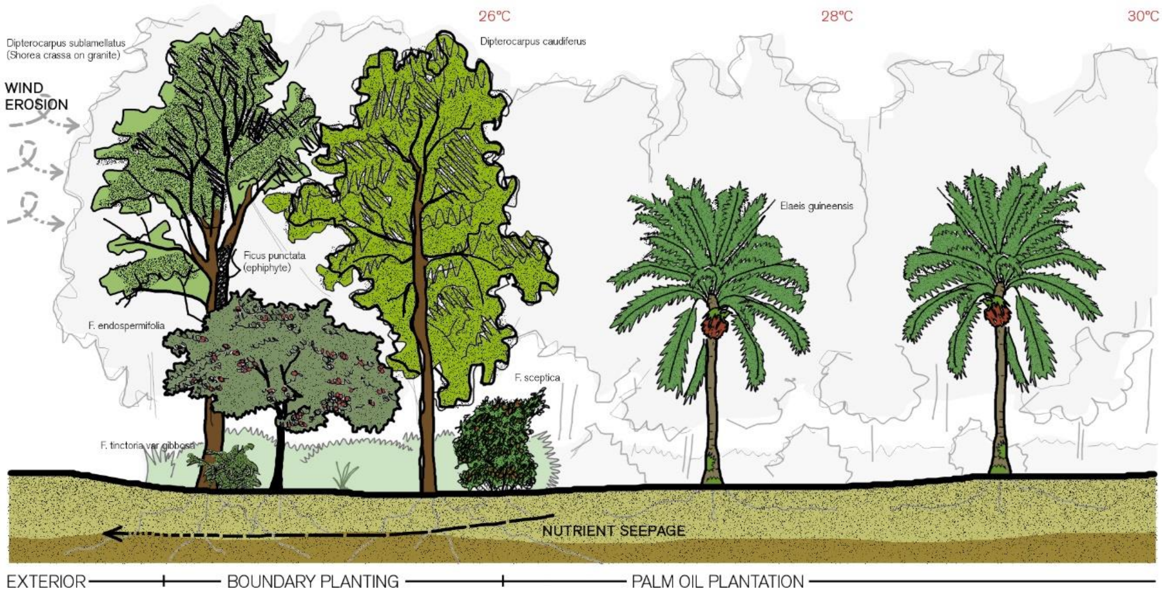


Figure 64. Typical section of the plantation boundary. Boundary planting is especially useful for marking out property, preventing nutrient seepage (through soil) and protecting (immature) oil palms from wind erosion. Alternative vegetation can be found in attachment 1.

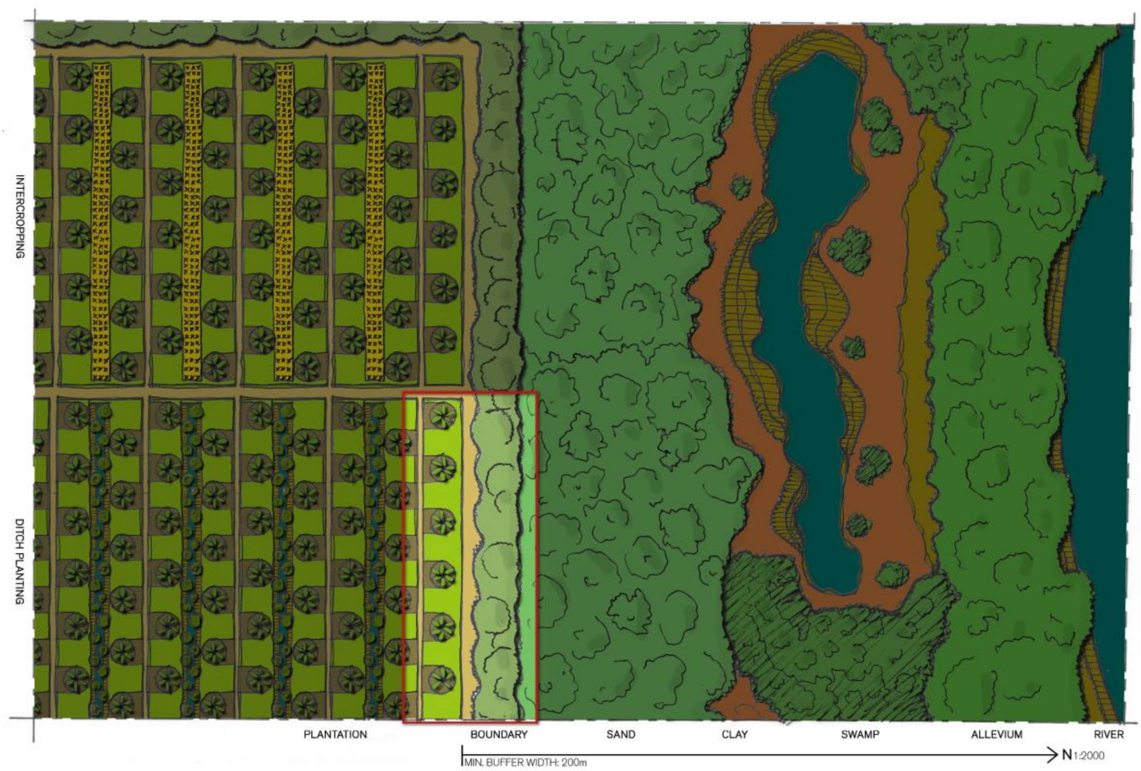


Figure 65. Spotlight: Location (top view) of the section above within the plantation.

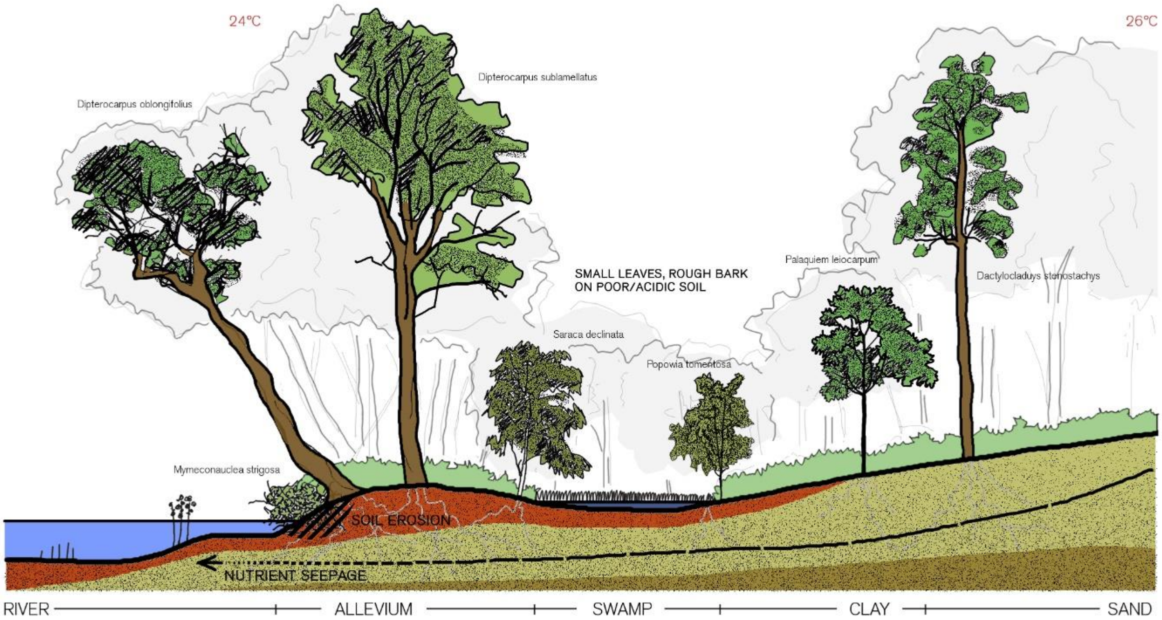


Figure 66. Typical section of the riparian buffer. Plantations in Indonesia are required to be 200m away from major rivers, to prevent nutrient seepage and a decrease in water quality. In practice, spontaneous expansion often happens towards and within these zones. Water quality is important as most of the population lives on river shores.

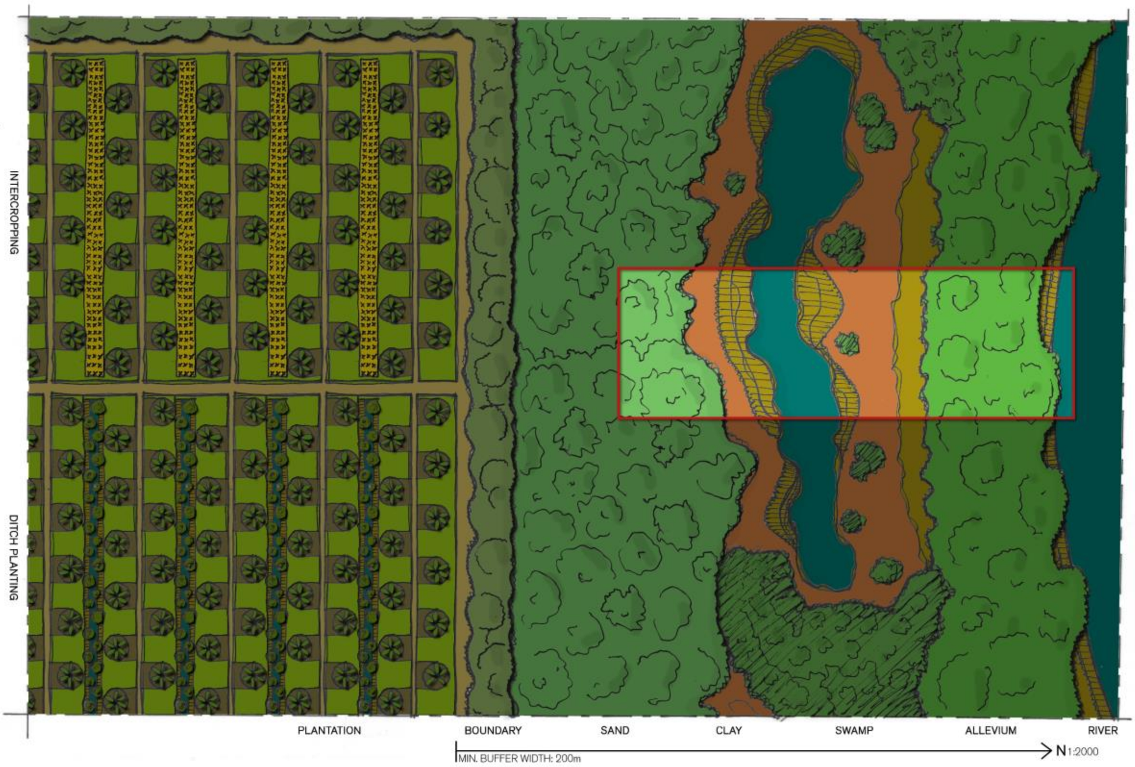
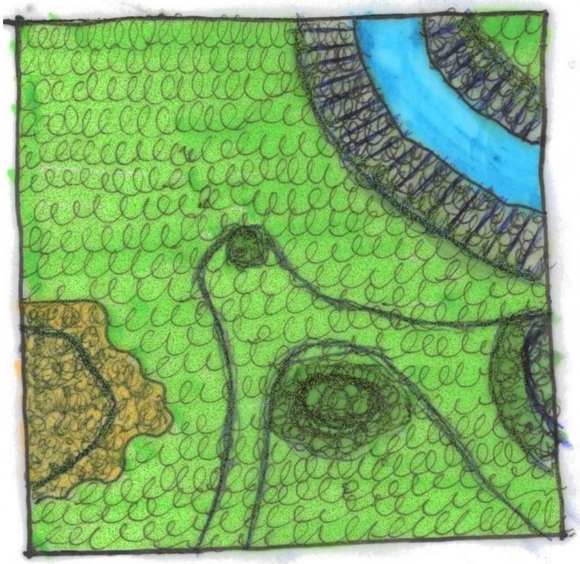


Figure 67. Spotlight: Location (top view) of the section above within the plantation.

5.9 PHASING THE CYCLE



t<0 (pre-establishment)

Legend

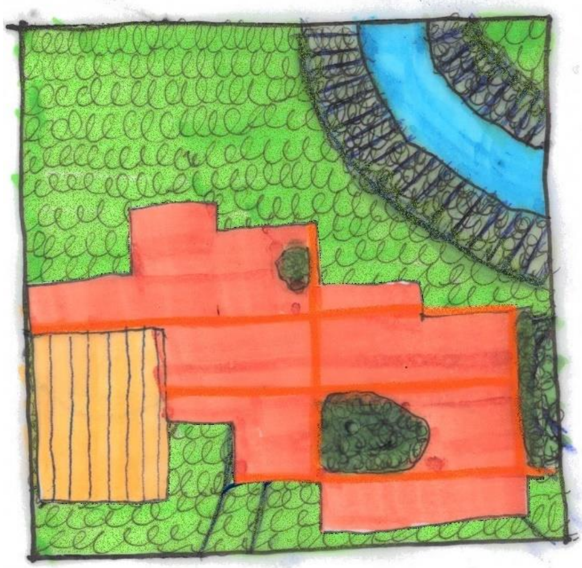
1:2000 ^ N

- Degraded forest
- Forest patches
- Peatland
- River

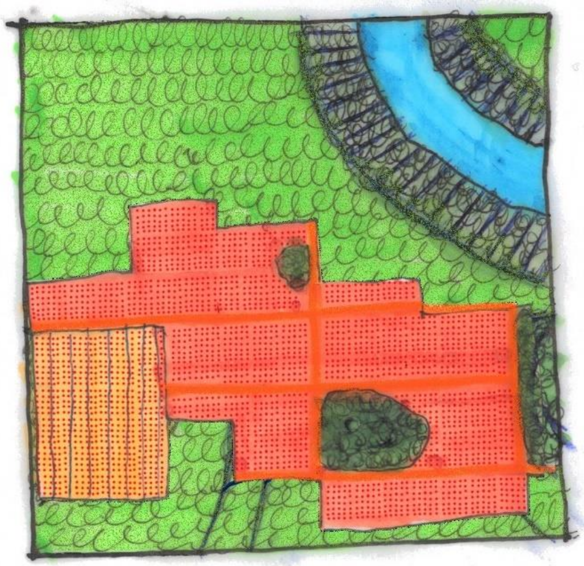
- Heightlines
- Riparian buffer (200m)

- Plantation
- Plantation road
- Oil palm seedling
- Oil palm mature
- Drainage ditches

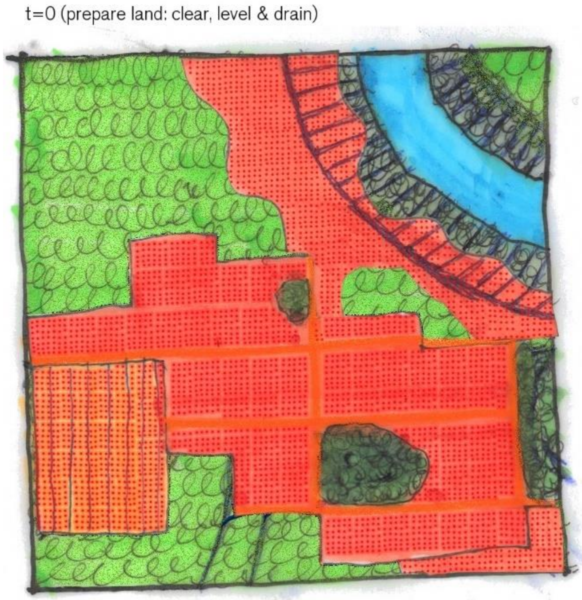
- Boundary planting
- Ditch planting
- Wetlands
- Cover cropping
- Intercropping



t=0 (prepare land: clear, level & drain)



t<5yr (pre-productive, vegetative stage)



t<25yr (production & expansion)

t>25yr (end of the harvest cycle, clear & start over)

Figure 68. Current JL. Nangah Pinoh production cycle (left) and phasing the RSPO+ countermeasures (right). from above (1:20k)

RSPO+ spatial vision

t<0 (Jl. Nangah Pinoh at the end of the previous harvest cycle)

t=0 (boundary planting: flower in landlocked north, fruit in south)

t=0 (ditch planting, restoring riparian buffer)

t=0 (integrate patches, migratory corridors)

t<5yr (planting new grid, intercropping & cover cropping adjacent)

t=10yr (planting previously cover cropped, varying standing age)

5.10 CONCLUSION

For reasons such as microclimate, erosion and pest control, filtering out nutrient (pollutants) or supporting wildlife by providing required habitat complexity, a more ambitious spatial standard for RSPO palm oil plantations is proposed. Key measures include intercropping, ditch planting, boundary planting and restoring riparian buffer zones. This spatial standard is showcased in a design experiment for a (pilot) plantation in the Melawi Regency and can be applied to similar contexts.

6.1 CONCLUSIONS

How can palm oil plantations in Kalimantan spatially adapt to reinstate native biodiversity, while lowering environmental impact, within a changing climate?

Palm oil plantations have been rapidly expanding on the Indonesian island of Kalimantan. The emerging monoculture sacrifices biodiversity and environmental services compared to the original forest. Between 1973 and 2015, the share of Kalimantan's surface area covered with primary forest went down from 61% to just 18%. It is estimated that palm oil plantation expansion causes half of this deforestation.

Oil palm plantations significantly alter the ruling microclimate. Compared to forest, their canopies are less dense and the leaf area index is lower. In oil palm plantations on Kalimantan, mean maximum air temperatures were up +6,5∘C from primary forest and +4∘C in relation to logged forest (Hardwick et al., 2015). While forest usually can only burn during (extreme) moisture stress (Cochrane, 2003), palm oil plantations are more flammable as they are generally more exposed to elements and drier. Fragmentation (caused by large scale land-use change) elevates tree mortality around edges and in pockets. The assimilated dead branches and biomass are easily ignited and can start canopy fires.

Land clearing, the use of heavy machinery and traffic are causes of soil compaction, reducing the infiltration rate of the soil. This decreases the water storage (buffer) ability of the ecosystem, raising vulnerability to both floods and drought. Land clearing (using fire or drainage practices) additionally can cause the groundwater table to rise above the soil surface during periods of heavy rainfall, flooding the area from below (a phenomenon called soil subsidence).

The use of fertilizer is another reason for environmental concern. This could be alleviated by mulching or composting waste biomass produced by the plantation. Instead of collection at mills, where biomass or manure first needs to be transported to (with empty lorries returning) the nutrients originating from a plantation should be kept in the system to achieve circularity. To stimulate soil biota, composting should be done in anaerobic conditions, possibly under water, roof or plastic. Mixing dry biomass with wet dredging soil brings enzymes in, characterized by their produced heat and damp. Cover cropping and intercropping (varying nutrient demand) reduces standing pools of nutrient 'overshoot'. Mulched pathways have a third of the soil loss compared to pathways left bare.

The climate in Western-Kalimantan is consistently warm and wet. Southern and Eastern regions receive less rainfall compared to the rest of the island. Climate change is expected to increase precipitation island wide.

Efforts geared towards improving biodiversity on oil palm plantations hinge on achieving spatial complexity (Koh et al., 2009). Plantations need encouragement to vary in canopy height, canopy cover and understory. Unplanted areas (especially adjacent to forest) can be maximized by maintaining native vegetation (Dislich C, 2017). Species richness takes a heavy blow when converting forest to oil palm, decreasing effectiveness of biological control of pests and diseases. Monocultures provide limited options for animals to gather food and shelter.

In addition to introducing (native) forest and understory, the habitat structure could be made more complex by varying the standing ages of different oil palm ‘compartments’. Rather than planting all trees at once, cover crops can be planted in (temporarily) bare compartments. Monoculture drawbacks scale with the size of the plantation, as canopy cover varies widely (20 to 70%) between plantation edge and core. For this reason, regenerative strategies should be targeted at industrial plantations. 85% of plantation surface on Kalimantan is industrial (Gaveau, 2021).

Lowland forest species are most affected by deforestation and climate change. Small birds feed on a diet of insects, which in turns requires understory and flowering vegetation. Orangutans and large birds require loads of fruit, fig seems popular (few remain in the wild or are scattered). Regenerative interventions should first focus on areas of strength (in proximity to pristine nature).

For reasons such as microclimate, erosion and pest control, filtering out nutrient (pollutants) or supporting wildlife by providing required habitat complexity, spatial standard for palm oil plantations is introduced. Key measures include intercropping, ditch planting, boundary planting and restoring riparian buffer zones. This spatial standard is showcased in a design experiment for a (pilot) plantation in the Melawi Regency and can be applied to similar contexts.

6.2 REFLECTION

To make this reflection critical, different perspectives have been considered (which will all be featured separately below).

- Preparation

During last year's summer break, I had no potential graduation subjects yet in mind. Surely it would have to do with climate change and spatial adaption, but I was keen to try something different than flooding (the Dutch context). Looking back, this risk was taken quite carelessly: Both Kalimantan and data about Kalimantan are not easily 'reachable' (unsurprising given the small population and Indonesian as main language). The discussion on palm oil (and issues regarding it) was more polarised than anticipated to be, making it harder to find objective sources and thus to stay objective myself.

Yes, I do care about pristine nature and the species existing in this world, but I am not naïve enough to think palm oil has no place in it. There is great economic potential, just environmental costs should be considered and reasonably limited: Existing in harmony with (the richness of) the landscape requires sacrifice but could be possible within 'usual' intensities of 150 palms/hectare.

Both RSPO and most literature refrain from sharing principles (recipes) for achieving spatial complexity, based on the notion that every location is unique. While undoubtedly true, this means uniformity (or a spatial standard) for sustainable plantations is lacking. Certification requires regular visits from advisors (expensive) and plantation holders do not completely know what they can expect beforehand. Like in the case of the 12 design principles for urban space of Jan Gehl, the principles and analysis should be used as a general starting point for design (or more research).

- Structure and rhythm

With little inspiration (thought and talk) going into the graduation period, the decision to work on palm oil in Kalimantan was made relatively late (after the P1 which was still about wildfires without a specific location). This delay, in combination with unfamiliarity to the subject meant that the analysis part (targeting specific information and understanding it) left not much time for the design. While plantation (layout) design usually do not rely on elaborate renderings or perspective drawings, I still feel the need to showcase possessing the required skill. I do not regret taking my time in the process of selecting a subject (and analysing it), as eventually it sent me in the right direction and it taught me (many) new insights. Analysis is arguably as useful to the palm oil industry (or related research), since design remains a personal conception that will always require local adaptation.

Concerning rhythm, after a presentation it always took some time to get back up to speed. Throughout the rest of my education at TU Delft, projects are almost rushed through, with deadlines in short succession. Perhaps I still require a tight schedule to work at maximum concentration (productivity). While characteristically human, being stricter for myself could help me professionalise.

- Interpersonal

Graduating is an individual assignment yet you are not totally alone. Doing the intensives at the start of the year was a good way of getting to know teachers and fellow UM+C students. Although we all went our own directions, it was nice to bump into each other and share how it was going. Usually we would encounter the same hurdles.

The main reason why an inconsistent working rhythm is impractical is because it allows me to gather less feedback from my mentors. To improve, I should probably seek more contact and share progress. Despite I always felt supported (trusted in a way) by Arjan and Roberto, but also the other teachers within UM+C.

- Recommendations for future grads

Although somewhat tame, choosing a subject earlier touched upon in the curriculum ends in the best results. Do not choose a large problem far away, 'manageable' is important. Check beforehand if enough data is available on the subject, whether other students have attempted something similar.

If you are stubborn, and care about societal interest rather than practicality: In your personal life, it can make you more stressed or distant, interrupting relationships. Then it is especially important to maintain expressing your emotions towards lovers, friends but also teachers.

6.3 SUBJECT CHOICE

Initially, this research project focused on wildfires and how urban settlements could be made more resilient against them. When it comes to climate adaptation in Urbanism (especially at TU Delft), emphasis is put on resilience against flooding. Throughout my education, the natural counterpart of flooding (wildfire) remained untouched. While in the context of the Netherlands floods are paramount to the damage caused by fire, climate change increases the likelihood of wildfires occurring (globally).

Floods and wildfire can be considered similar extreme weather events in the sense that it is nature's way of starting with a clean sheet. The existing landscape is destructed but becomes more suitable (fertile) for the next generation to grow on. Contradictory, the fuel of fire is discontinuous: it consumes that which feeds it, eventually running out of available material to burn (after it will die out). Floods are guided by the continuous inclination of the valley, only ending when the sea has been reached. Human populations should be protected against these deadly events (in the case of wildfire also indirectly through hazardous air pollution). Additionally, any land use effort is undone, potentially leaving cultivated land in poverty.

In the global context, most research geared towards wildfires is about the context of California. A famous, developed state where people's homes are threatened. This starting point, where already countless measures are in place taught me that supressing wildfire can be paradoxical: Without wildfire, the forest grows dense and old, as (dead) biomass piles up on the surface. Essentially, forest where natural wildfires are supressed becomes more susceptible for (extreme) wildfires in the long term. The same way of thinking can be applied to human populations supressing disease: We grow older and live more densely packed, increasing vulnerability to new (more catastrophic) diseases. I do not propose abandoning healthcare, it is a realisation of what challenges we could be facing in (urbanism of) the future.

Disregarding California, as they can fetch for themselves, I looked on for a more developing context where the scale (challenge) of wildfire was enormous and the cause clearly human (counter able). The choice was then between Brazil and Indonesia. These countries include the largest, most biodiverse rainforests in the world (in the sparsely populated and inaccessible parts), but at the same time face the most rapid deforestation due to policies pursuing aggressive natural resource extraction and cultivation (of soy bean and palm oil respectively).

Having read the title, it would come as no surprise that I opted for Indonesia. Not only have I visited in 2019 (feeling a connection with the Indonesian people), the Netherlands imports more palm oil per capita than any other country in the world (giving me a sense of responsibility) and the problem is largely unbeknown to the public. Existing research about Indonesian palm oil is fragmented, sometimes contradictory (dependable on the interests of the publisher). It goes further than wildfire alone, as the plantations are a source of income, while at the same time a source of headache for their environmental and biodiversity (monoculture, maximizing yield) performance, similar (applicable) to agriculture in other, more familiar, contexts.

While I count the Indonesian people as one of the most friendly and hospitable, being the world's leading producer of palm oil is for many a source of (income or) national pride. What (foreign) research there is on the subject can then be regarded as outside interference. For this reason, I must state that the research ahead is merely educational (with sources selected by reliability), free of commercial interest. Being from a sparsely inhabited island (with less people, but pristine ecosystems) myself, leads me to believe that conserving (large plots of) wild nature far away is as, if not more important than introducing green into immediate surroundings (the city, where it does not belong or thrive to the fullest).

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ATTACHMENT 1: ALTERNATIVE VEGETATION

The following tables are derived from (Kade, Zakaria, & Iwan, 2006) and show the dominant species occurring in (intact) primary forest on Kalimantan for some habitats. The complete source is accessible through https://www.cifor.org/publications/pdf_files/books/BSidiyasa0601E.pdf

Importance Value Index (IVI) calculations for tree species that make up the forest show that in Sengayan the dominant species was *keruing* with an IVI of 36.07% and a density value of 18.38 stems/ha. Next was *ulin* with an IVI of 29.27% and density value of 15.38 stems/ha. Complete figures are presented in Table 12 and Appendix 16. It is quite clear from Table 12 that the forest stands are dominated by tree species from the Dipterocarpaceae family. Only 3 of the 10 dominant species were not Dipterocarpaceae. These three species were *ulin* (*Eusideroxylon zwageri*, Lauraceae), *Nyatoh* (*Palaquium*, Sapotaceae) and *Limpas* (*Koompassia malaccensis*, Leguminosae). *Tengkawang*, an important commodity as producer of *tengkawang* nuts was the sixth most dominant species.

Table 12. 10 species of mature trees with the highest Importance Value Indices (IVI) in Sengayan's forest

No	Tree type	KJ (n/Ha)	KR %	FJ	FR %	DJ (m²/Ha)	DR %	IVI %
1.	*Keruing*	18.38	15.89	0.25	5.26	4.77	14.91	36.07
2.	*Ulin*	15.38	13.30	0.25	5.26	3.42	10.71	29.27
3.	*Meranti Merah*	8.63	7.46	0.25	5.26	4.55	14.24	26.96
4.	*Meranti Putih*	7.63	6.59	0.25	5.26	3.15	9.86	21.72
5.	*Urat Mata*	3.63	3.14	0.23	4.74	2.56	8.00	15.87
6.	*Tengkawang*	6.25	5.41	0.25	5.26	1.58	4.94	15.61
7.	*Nyatoh*	6.25	5.41	0.25	5.26	1.16	3.62	14.29
8.	*Limpas*	4.50	3.89	0.25	5.26	1.60	5.02	14.17
9.	*Meranti Kuning*	4.75	4.11	0.25	5.26	1.43	4.47	13.19
10.	*Kapur*	4.00	3.46	0.25	5.26	1.43	4.47	10.49

Table 15. Habitats for each of the protected species commonly used by communities in Setulang and Sengayan

No.	Species (Latin name)	Local / trade name	Habitat type
1	*Eusideroxylon zwageri*	*Ulin, belian*	A, B, C
2	*Grammatophyllum speciosum*	*Anggrek tebu*	E-A
3	*Shorea macrophylla*	*Tengkawang*	A, (B)
4	*Shorea pinanga*	*Tengkawang*	A, B
5	*Shorea beccariana*	*Tengkawang burung*	(B), C, D
6	*Shorea seminis*	-	A, B, (C)
7	*Dyera costulata*	*Jelutung gunung*	C. D
8	*Palaquium gutta*	*Ketipai*	C, D
9	*Koompassia excelsa*	*Banggeris*	A, B, C
10	*Pangium edule*	*Payang*	A
11	*Aquilaria beccariana*	*Gaharu*	A, B
12	*Caryota no*	-	A
13	*Korthalsia echinometra*	*Rotan merah*	(B), C, D
14	*Calamus caesius*	*Rotan sega*	A, B, C, (D)
15	*Calamus javensis*	*Rotan lilin*	B, C, D
16	*Calamus pogonocanthus*	*Rotan semule*	A, B
17	*Daemonorops sabut*	*Rotan gelang*	A, B, C, (D)

Key: A = banks of rivers and tributaries; B = bottoms of slopes; C = tops of slopes and hilltops; D = hilltops; E = epiphyte. Letters (habitat types) in parentheses [()] indicate uncommon habitat.

Figure 9. *Dipterocarpus oblongifolius* one tree species characteristic to riverbanks (left) *Myrmeconauclea strigosa* protects riverbanks from erosion and landslides (right)

Results of vegetation surveys from 12 observation quadrats (7 in Setulang and 5 in Sengayan) (Table 18) show that in Sengayan's forest *Dipterocarpus oblongifolius* and *Saraca declinata* almost always grow alongside each other, but the former is much more dominant with a much higher IVI. However, this is only because the *Dipterocarpus* generally has large stems. In contrast, on riverbanks in Sengayan's *Tana Olen* forest, no other tree species showed a tendency to grow alongside *Saraca declinata*, which is the dominant species.

Table 18. Five dominant tree species found near riverbanks in forests in Setulang (a) and Sengayan (b).

Species / Genera	N	Q	BA	Freq	IVI
a. Setulang					
Saraca declinata	10	7	2.37	1.00	99.24
Shorea macrophylla	2	2	0.52	0.29	22.86
Shorea seminis	3	2	0.23	0.29	18.86
Syzygium sp.	2	2	0.17	0.29	15.11
Shorea johorensis	2	2	0.16	0.29	14.71
b. Sengayan					
Dipterocarpus oblongifolius	5	4	3.97	0.80	81.82
Saraca declinata	4	3	0.92	0.60	32.37
Pentaspadon motleyi	2	2	0.23	0.40	14.26
Mallotus muticus	2	2	0.02	0.40	11.25
Syzygium sp.	2	2	0.02	0.40	11.25

Key: N = number of trees; Q = number of quadrats; BA = basal area (m2); Freq = frequency; IVI = Importance Value Index.

Table 7. 10 species of saplings with the highest Importance Value Indices (IVI) in Setulang's *Tana Olen* forest

No.	Tree type	Kj(n/Ha)	Kr (%)	Fj	Fr (%)	IVI
1	*Pisang-pisang (Beteny)*	210.853	5.097	0.213	4.041	9.139
2	*Nyatoh (Kaze Nyatu)*	187.597	4.535	0.205	3.894	8.429
3	*Meranti Merah (Kaze Tenak Bala)*	212.403	5.135	0.163	3.086	8.221
4	*Sengtung*	159.690	3.861	0.194	3.674	7.534
5	*Selafung*	147.287	3.561	0.198	3.747	7.308
6	*Darah-darah (Kaze Nyera'a)*	139.535	3.373	0.202	3.821	7.194
7	*Kaze Nyak*	147.287	3.561	0.174	3.306	6.867
8	*Uno Bangat*	155.039	3.748	0.159	3.012	6.761
9	*Apang Bule*	124.031	2.999	0.151	2.866	5.864
10	*Ubah (Ubo)*	124.031	2.999	0.143	2.719	5.717

Table 8. 10 species of small trees with the highest Importance Value Indices (IVI) in Setulang's *Tana Olen* forest

No	Tree type	KJ (n/Ha)	KR %	FJ	FR %	DJ (m^2/Ha)	DR %	IVI %
1	*Meranti Putih (Kaze Tenak Futi)*	31.395	6.444	0.217	5.556	0.529	6.769	18.769
2	*Kajen Ase*	27.132	5.569	0.190	4.861	0.432	5.528	15.958
3	*Meranti Merah (Kaze Tenak Bala)*	26.744	5.489	0.163	4.167	0.474	6.066	15.722
4	*Nyatoh (Kaze Nyatu)*	19.380	3.978	0.136	3.472	0.337	4.316	11.766
5	*Darah-darah (Kaze Nyera'a)*	19.767	4.057	0.143	3.671	0.309	3.961	11.689
6	*Ubah (Ubo)*	16.279	3.341	0.132	3.373	0.260	3.326	10.040
7	*Uno Bangat*	14.729	3.023	0.116	2.976	0.218	2.787	8.786
8	*Tengkawang*	14.729	3.023	0.101	2.579	0.244	3.128	8.730
9	*Apang Bule*	14.341	2.944	0.109	2.778	0.213	2.729	8.451
10	*Bebeveny*	13.566	2.784	0.112	2.877	0.217	2.784	8.446

	OBS				
	A	**S**	**G**	**W**	**P**
Popowia tomentosa (*Annonaceae*)	1	1	0	12	0
Bhesa paniculata (*Celastraceae*)	0	1	1	0	7
Atuna racemosa (*Chrysobalanaceae*)	2	9	1	0	0
Dactylocladus stenostachys (*Crypteroniaceae*)	2	0	0	1	40
Dipterocarpus sublamellatus (*Dipterocarpaceae*)	38	26	15	0	0
Shorea crassa (*Dipterocarpaceae*)	0	0	26	0	0
Shorea quadrinervis (*Dipterocarpaceae*)	0	0	18	0	0
Fahrenheitia pendula (*Euphorbiaceae*)	1	9	3	0	0
Pimeleodendron griffithianum (*Euphorbiaceae*)	0	2	5	0	13
Archidendron sp. 1 (*Fabaceae*)	0	0	0	3	7
Dialium spec. 1 (*Fabaceae*)	3	2	0	3	0
Sindora spec. 2 (*Fabaceae*)	0	0	0	2	6
Stemonurus spec.1 (*Icacinaceae*)	1	0	0	1	13
Stemonurus secundifolius (*Icacinaceae*)	0	3	0	0	24
Eusideroxylon zwageri (*Lauraceae*)	3	6	0	2	0
Pternandra coerluscens (*Melastomataceae*)	5	1	2	30	1
Artocarpus kemando (*Moraceae*)	2	0	0	7	0
Syzygium spec. 1 (*Myrtaceae*)	17	1	1	1	6
Syzygium spec. 60 (*Myrtaceae*)	1	0	12	0	6
Strombosia ceylanica (*Olacaceae*)	7	28	8	0	1
Ochanostachys amentacea (*Olacaceae*)	9	8	0	6	0
Xanthophyllum spec. 2 (*Polygalaceae*)	0	0	0	0	19
Nauclea spec. 2 (*Rubiaceae*)	0	0	0	0	24
Palaquium leiocarpum (*Sapotaceae*)	0	0	0	1	54
Palaquium spec. 5 (*Sapotaceae*)	0	1	19	0	0
Scaphium macropodum (*Sterculiaceae*)	0	2	7	2	1
Gironniera spec.1-cc (*Ulmaceae*)	7	1	0	0	0

Dominant species on different soil types.

A=Alluvium, S=Sandstone…, granite, swamp, peat