Reforesting for the climate of tomorrow

Recommendations for strengthening orangutan conservation and climate change resilience in Kutai National Park, Indonesia

Alan Tristram Kenneth Lee, Jamie Anthony Carr, Busran Ahmad, Arbainsyah, Agnes Ferisa, Yophi Handoko, Rudi Harsono, Laura Graham, Lita Kabangnga, Nur Patria Kurniawan, Paul Joseph Antonius Keßler, Purwo Kuncoro, Dinda Prayunita, Aldrianto Priadjati, Edy Purwanto, Anne Russon, Douglas Sheil, Nurul Sylva, Agus Wahyudi, Wendy Foden

SSC Species Survival Commission

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Executive summary

In Indonesia, **Kutai National Park** is home to what is likely to be East Kalimantan's largest population of the Critically Endangered eastern subspecies of the Bornean Orangutan, *Pongo pygmaeus morio*. It also hosts an astounding diversity of other species including ~80 mammal, 369 bird and 1287 plant species. The park plays an important role in regulating water supply to neighbouring towns, attracts tourism and its forests serve as a valuable carbon sink.

Yet East Kalimantan faces many challenges in maintaining and protecting biodiversity from threats, particularly from population expansion into the protected area with associated hunting and forest clearing for agriculture, fire, and coal mining. More recently, climate change has been identified as an emerging threat, with both observed and projected changes indicating with high confidence that higher temperatures are to be expected. These are likely to exacerbate drought conditions, which enable wildfires and lead to a range of other negative impacts on the species of **Kutai National Park**. To date, however, few initiatives have attempted to assess the vulnerability of the region's biodiversity to climate change, nor to develop strategies to minimise negative impacts.

Forest restoration, also referred to as reforestation, presents a valuable opportunity to restore biodiversity and function to degraded areas that were once forested. Reforestation initiatives are being carried out in **Kutai National Park**, ranging from protection to enrichment planting in areas that were previously burnt but are now recovering. While several of these programmes have successfully planted large numbers of seedlings, little attention has been placed on restoring species richness, ecological function or selecting species that are of value for orangutan survival. In addition, most fail to consider climate change and hence that selected species must be able to establish and survive in the warmer and drier climatic conditions of the future. There is a clear and pressing need to update **Kutai National Park's** existing restoration practices to ensure forest integrity, provide opportunities for threatened species, and guide consideration of how to build climate change resilience. By doing so, the forests that orangutans need to survive into the future are more likely to persist.

To meet the need for guidance on climate change resilient reforestation practices, we collaborated with park authorities and other experts to identify the tree species that are most vulnerable to climate change and those likely to be most climate change resilient. The importance of orangutans in **Kutai National Park's** conservation objectives led us to expand our scope to identify those tree species that are valuable resources for them, and this extended further to addressing the need for identification of those that are ecologically and commercially important; those that are iconic (have tourist potential); those that are most representative of primary forest; those resilient to fire; as well as those that are locally threatened. To assess climate change vulnerability and resilience, we examined the biological characteristics or traits of species that are associated with their sensitivity and/or adaptive capacity to the anticipated climate changes and the resulting altered fire regimes.

We examine restoration case studies, remind readers of restoration best practice, and present sets of tree species from a set of ~250 considered in the analysis that are likely to be suited to various restoration targets for **Kutai National Park**, e.g. with a focus on habitat restoration for orangutan; or a focus on conservation of rare and useful species. Given the fire prone nature of the area, two species stand out due to their resilience to fire events: *Borassodendron borneense,* and *Eusideroxylon zwageri*: known locally as Bendang and Ulin respectively. The following species emerged as most important food plants for Orangutan: *Dracontomelon dao, Merremia mammosa, Kleinhovia hospita, Alangium hirsutum, Dillenia reticulata, Callicarpa pentandra,* and *Ficus obpyramidata.* Species that are most likely to be climate change resilient were dominated by pioneer or invasive species.

It emerged from workshops held in Bontang, Indonesia, that supply of seedlings for restoration projects is a challenge. Special provision must also be made for the collection of seedlings for masting species, as these events provide a rare opportunity to source otherwise rare stock for key species such as those of the Dipterocarpaceae. This family in particular emerged as vulnerable to climate change, but also one that is regionally important. Furthermore, the success of any restoration project lies in addressing the issues that lead to deforestation in the first place. These issues need to be addressed and long term monitoring needs to be in place to ensure the success of all restoration projects.

The intended audiences of this work include: orangutan researchers, government, mining companies, nurseries and other companies that are seeking guidance on habitat restoration for climate change resilience in East Kalimantan, as well as those wishing to support biodiversity conservation and/or restoration in the region.

Introduction

Borneo's forests possess some of the richest biological communities on the planet. This biodiversity is a treasure trove of resources that can also benefit human livelihoods (Caniago and Stephen 1998). The forests provide a broad range of ecosystem services, probably the most important of which is the provision of water (Limberg et al. 2009), but also mediation of potential flood damage (Stadtmueller 1990). Protected forests are also an important recreation and tourism resource, especially where they are home to flagship species such as the orangutan (Gunn and Var 2002, Russell and Ankenman 1996). Borneo's forests provide important food resources for those who have learned to use them (Peluso 1992), and serve as valuable carbon sinks (Pan et al. 2011). However, the alarming current levels of forest loss and degradation is leading to a reversal of this role, with forests becoming sources of carbon dioxide emissions. This underscores the role of forest conservation and restoration in maintaining planetary life-support systems (Baccini et al. 2017)

Borneo's exceptional forest species richness is likely to be underpinned by the region's varied geological history, with the variety of geological types and processes giving rise to a broad range of soil types. Combined with recent geological stability (Hall and Holloway 1998) and moderate climate change over past millennia, these have created mixed tree communities that vary in a fine-grained mosaic pattern (Potts et al. 2002). Limited seed dispersal means that distant communities evolve independently of one another, resulting in high species diversity across the landscape (gamma diversity). While forested sites with temperate climate are generally dominated by a few well known species of tall trees, the large number of rare species means that it is still a struggle to identify all plants to species level (e.g. Cannon and Leighton (2004)).

Borneo has become the focus for conservation activities both because of its biological richness and due to the level of threats that this biodiversity faces. Borneo lies within the Sundaland global biodiversity hotspot (Whitten et al. 2004) and is also a hotspot for biodiversity itself (de Bruyn et al. 2014, Kier et al. 2005). Most of the island's forests are dominated by tree species in one family, the Dipterocarpaceae, a family of tall primary forest trees often targeted for their timber. While these species do not provide food resources for frugivores (Meijaard et al. 2005), the island nonetheless hosts many remarkable forest animals, including the endemic and fruit seeking Bornean orangutan *(Pongo pygmaeus)*, which is considered vulnerable to extinction due to habitat loss and other threats (Wich et al. 2012). Borneo's forest cover has declined nearly twice as fast as the rest of the world's humid tropical forests (Gaveau et al. 2016, Gaveau et al. 2014).

While impacts of forest loss from deforestation and mining have been well studied, the emerging threat from climate change has been relatively poorly explored. There is clear evidence that Borneo's climate is changing, with notable increasing temperatures, prolonged dry seasons, and conditions suitable for wildfires. Climate change impacts have the ability to undermine all other conservation efforts, but there is relatively little literature on forest resilience to climate change.

Forest restoration provides a unique opportunity to shape forests for future use and climate change resilience. There are multiple restoration activities underway across Borneo, and in Kutai National Park. Within Kutai National Park, consideration in restoration must be given to the last remaining population of the Critically Endangered Bornean orangutan as these forests represent the last stronghold for this species in Indonesia. Orangutans are forest-dependent species, with morphology, social behaviour and intelligence all shaped by, and for, life in the forest. Landscapes devoid of forest will also be devoid of orangutans, underscoring the clear link between their survival and forest conservation. As such, what can the conservation community do to ensure that tropical forests such as those at Kutai National Park remain in condition that can sustain orangutan populations? We suggest:

1. Protecting remaining forests from forest clearing. This is urgent and of greatest priority.
2. Protecting forests from fires arising in adjacent areas. Planning buffer areas that are fire-resilient and fire-resistant is important, so vegetation that can fulfil this function should be identified and established in buffers.
3. Restoring forests in key areas, in order to maintain connectivity and increase orangutan habitat and in a way that ensures forests are resilient to threats associated with a changing climate.

Study objective

This study focuses primarily on providing the information to inform the choice of tree species for forest restoration that are likely to be resilient to climate change, including identifying fire-resilient species that may help to meet goals of reducing fire exposure. Key considerations when planning forest restoration include:

1. Identifying which tree species occur in Kutai National Park
2. Quantifying which tree species are vulnerable to climate change, as well as those which may be most resilient to climatic conditions of the future
3. Identifying which tree species are of greatest importance as food and nestnig sources for orangutans
4. Understanding which tree species are of greatest importance for other reasons, namely because of their high value:
    a. Economically
    b. Ecologically
    c. Culturally (e.g. iconic species, or local use)
    d. Old growth species (associated with high above ground carbon stocks)
5. Identifying which tree species are vulnerable to declines and/or extinction due to non-climatic threats e.g. habitat loss or overharvesting
6. Identifying which tree species are most fire-resilient

A key additional criterion for consideration is which of these species are conducive to cultivation, transplanting and restoration activities. While we explore the limited literature on this subject, a comprehensive assessment is beyond the scope of this report.

Kutai National Park

Kutai National Park (KNP) was originally established in 1934 by the Netherlands (then the Royal Government of Kutai) as a 2 million ha nature reserve. In 1995 the status of the park was designated a national park, but its area was reduced in size to 198,629 ha. In 2014 the area was reduced again to 192,709 ha due to human settlement within KNP (see more on this in the threats section). Today, park authorities state that the main reason the park exists is for protection of orangutan, proboscis monkey *(Nasalis larvatus)*, Malayan sunbear *(Helarctos malayanus)* and the Javan banteng *(Bos javanicus)*. However, the current **'national park'** protection status does not prevent illegal activities including logging, wildlife poaching and forest clearing for small scale agriculture, and constant encroachment of people along the eastern boundary continues to reduce the true park area (Limberg et al. 2009). KNP authorities are now making efforts to maintain, restore and protect KNP's forests and the wildlife they contain.

The forests of KNP represent one of the last intact forest canopies of East Kalimantan, with remarkable botanical richness. At the generic level, tree-diversity is highest in south-east Borneo and central Sarawak (Slik et al. 2003). Kutai National Park, like most of Borneo, is dominated by lowland tropical forest, where the main tree species are members of the Dipterocarpaceae. The other vegetation types include coastal mangrove forest, riverine/alluvial forest, freshwater swamp forest and kerangas (heath) forest. As one of the last remaining areas of tropical lowland rainforest its value as a gene pool and seed bank is high (Moeliono and Purwanto 2008).

Mangrove forests, Bontang

Proboscis Monkey (*Nasalis larvatus*)

There are ~80 mammal species, 369 bird species, 26 reptile species and 25 amphibian species currently recorded from KNP (TNK 2016). There is high primate species richness, including at least nine species. One of the most interesting is the subspecies of Hose's langur known as Miller's grizzled langur (*Presbytis hosei ssp canicrus*, Endangered), as KNP was one of the locations from which it was first identified in 1985. This is thought to be the rarest primate in Borneo (Lhota et al. 2012). The other eight primates include the east Bornean orangutan subspecies (*Pongo pygmaeus morio*, Critically Endangered), Müller's Bornean gibbon (also known as the grey gibbon, *Hylobates muelleri*, Endangered), proboscis monkey (*Nasalis larvatus*, Endangered), crab-eating macaque (or long-tailed macaque *Macaca fascicularis*, Least Concern), maroon leaf monkey (*Presbytis rubicunda*, Least Concern), white-fronted surili (*Presbytis frontata*, Vulnerable), southern pig-tailed macaque (*Macaca nemestrina*, Vulnerable), and a slow loris (likely after recent splitting of the Borneo slow loris, this is the Philippine slow loris (*Nycticebus menagensis*, Vulnerable)). There are also other threatened mammals such as the otter civet (*Cynogale bennettii*, Endangered) and clouded leopard (*Neofelis nebulosa*, Vulnerable).

Orange-backed Woodpecker (*Chrysocolaptes validus*)

Malayan Sunbear (*Helarctos malayanus*)

The number of bird species occurring in KNP stands at 369 species, and includes the Far Eastern Curlew (*Numenius madagascariensis*, Endangered) and Silvery Pigeon (*Columba argentina*, Critically Endangered), as well as a further 12 species classified as Vulnerable and 77 as Near Threatened. Unlike the animals, the threat status of the plant species has been less well quantified by the IUCN.

Visitors to KNP can view wildlife at three ecotourism sites: the recently opened **Bontang Mangrove Park**, focused on promoting mangrove conservation; **Sangkima**, a visitor centre on the Sangatta road with boardwalk and canopy-bridge and bird-hide where education is focused on biodiversity; and **Prevab**, a ranger station that hosts tourists and researchers. Prevab and another research station, Mentoko, are located on the Sangatta River on the northern border of the park. During 2016 KNP recorded 15,000 visitors. KNP's head offices are in Bontang. Projects undertaken by KNP staff include the construction of a walkway in the local mangrove swamps, and production of books on birds of KNP - *Burung Taman Nasional Kutai,* medicinal plants - *Tumbuhan obat Taman Nasional Kutai,* and flowering plants - *Tumbuhan hias Taman Nasional Kutai.* Recently, KNP management created a partnership called "Mitra Taman Nasional Kutai" (Friends of Kutai National Park) with several different companies located adjacent to the national park. The park authorities also collaborate with local coal mining companies for habitat restoration work in the park. Various research projects are conducted in collaboration with multiple different research institution and universities, such as York University (Canada) and Universitas Mulawarman, Samarinda (Indonesia).

Orangutan

KNP is a recognised stronghold for orangutan with a long history of research on these animals: its Mentoko forest was the site for seminal studies of orangutan behavior and ecology, including the first wild orangutan research in Indonesia (Rodman 1973, 1977). This research continues currently through the Orangutan Kutai Project (OKP: see Box 1). Orangutan are the flagship species of KNP, where these great apes can be seen in the forest with relative ease at certain sites.

There are three species of orangutan (genus *Pongo*): the Bornean orangutan (*P. pygmaeus*), the Sumatran orangutan (*P. abelii*) and the recently described Tapanuli orangutan (*P. tapanuliensis*), also found in Sumatra (Nater et al. 2017). All orangutans are primarily frugivores with a preference for ripe, soft pulp fruit (Wich et al. 2008). They are long-lived (up to ~55 years in the wild), very slow to develop and reproduce (~16 years birth to adulthood, one infant per birth at 6-9 yr intervals), and low in sociability (Wich et al. 2010).

Bornean Orangutan *(Pongo pygmaeus)*

The Bornean orangutan is restricted to Borneo. The most recent estimate of the total surviving Bornean orangutan population is 57,200 (PHVA 2017), which together with continued population decline prompted its reclassification from Endangered to Critically Endangered on the IUCN Red List (Ancrenaz et al. 2016a). Between 1999 and 2015, half of the orangutan population in Borneo was impacted by logging, deforestation, poaching or industrialized plantations, with estimations of a population decrease of more than 100,000 individuals (Voigt et al. 2018).

Three subspecies are currently recognized for *P. pygmaeus* (Ancrenaz et al. 2016b):

Northwest Bornean Orangutan *(P. p. pygmaeus)* which occurs in the state of Sarawak, (Malaysia) and province of West Kalimantan (Indonesia)

Southwest Bornean Orangutan *(P. p. wurmbii)* which occurs in the provinces of West Kalimantan and Central Kalimantan (Indonesia)

Northeast Bornean Orangutan *(P. p. morio)* which occurs in the state of Sabah (Malaysia) and provinces of North Kalimantan and East Kalimantan (Indonesia)

Northeast Bornean Orangutan (*P. p. morio*) unflanged adult male Gatot

Northeast Bornean Orangutan *(P. p. morio)*

The population estimate for the Northeast Bornean orangutan is 14,470, with only five large populations likely to have long term viability (PHVA 2017) (Box 1). The main population of the subspecies is in Sabah, Malaysia with an estimated 11,730 (SD ±1,560) individuals (PHVA 2017). KNP supports the last remaining large population of Northeast Bornean orangutan in Indonesia. The population estimate for East Kalimantan is 2,900 (SD ±750) individuals, with 1,700-1,930 in KNP (PHVA 2017, TNK 2016).

The main threats to Northeast Bornean orangutan, as listed by PHVA (2017) include: encroachment by small scale agriculture; illegal logging; habitat conversion for industrial agriculture; road construction; and poaching. While each threat has various potential mitigation strategies, a core element for dealing with all these threats is improved law enforcement (PHVA 2017).

Overall, Northeast Bornean orangutan survive where availability and predictability of preferred foods is among the lowest of all orangutan habitats (Table 1). East Borneo's forests are the most heavily dominated by dipterocarps, which are very infrequent producers of potential foods. The dipterocarp dominance further results in low availability of other fruiting species. East Borneo also experiences the most severe El Niño Southern Oscillation (ENSO) effects (see section of climate below). The resulting extreme variation in rainfall in turn causes major fluctuations in the availability of orangutan plant foods. Northeast Bornean orangutan diet is thus characterized by less fruit and more poor quality 'fall back' food species and items compared to other orangutan species (Russon et al. 2009). For the purpose of this report 'orangutan' refers to Northeast Bornean orangutan.

Orangutan in Kutai National Park

KNP's orangutans experience location-specific challenges due to the park's particular ecological conditions. These include the effects of ENSO events (for more on this see climate change section) with resulting severe drought and fire damage (1982-83, 1997-98). Forest recovery conditions and ongoing human impacts on the park's flora and fauna (see below) also impact orangutan survival. All three factors are important considerations in designing forest enrichment and restoration work.

Local ecological conditions

Orangutans range in most parts and habitats of the park. For example, the northern section of the park includes multiple forest types, largely determined by elevational gradient, including seasonally flooded alluvial forest and upland mixed diperterocarp lowland rainforest (Leighton 1993). Resident orangutans move back and forth between forest types, sometimes on a seasonal basis, suggesting that they require resources available in multiple different forest types (OKP unpublished).

ENSO

ENSO patterns can differ between locations within Borneo. In KNP, the El Niño phase causes extremely long, harsh droughts and La Niña causes very high rainfall (Qian et al. 2013). ENSO is a major driver of the very high variation in food availability that KNP orangutans face: El Niño brings droughts which result in food shortages and fire, while La Niña brings rains which enable rich plant growth resulting in food abundance. East Bornean forests and resident wildlife, including orangutans, have survived a long history of fluctuating ENSO extremes and are therefore able to cope with these high levels of change in their living conditions.

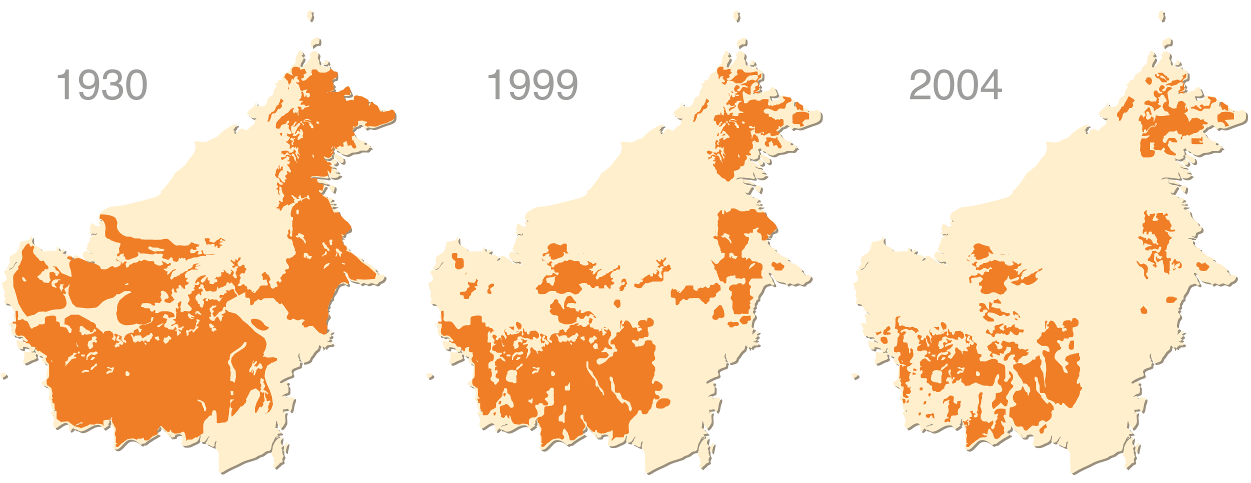


Figure 1. Change in orangutan distribution in Borneo between 1930 and 2004 (Hugo Ahlenius). Source: www.grida.no/resources/7755

Kutai National Park damage

Until the early 1980s, the park's forest was near pristine, and was damaged only by small scale logging and poaching. Commercial resource extraction industries then began expanding around the park, and severe El Niño droughts (1982-83, 1997-98) followed by the 'Great Fires of Borneo' twice degraded large proportions of KNP's forests. The droughts were natural events, but the fires were caused by humans. The second fires destroyed 90% of the park's forests and most people, including researchers and conservationists, mistakenly concluded that the forest was unrecoverable and the park's orangutans almost extinct. Both drought-fire disasters markedly affected the park's orangutans. In KNP's northern Mentoko area, the 1982-83 drought and fires destroyed most of the orangutans' known major food sources and seriously damaged most of those that survived (Leighton and Wirawan 1986). Despite the extreme food shortages these orangutans faced, especially fruit and loss of many trees and lianas they had used for arboreal travel, most survived, largely through increased reliance on very poor quality foods (e.g. bark, some leaves and new shoots) and altering behavior to reduce energy expenditure (Leighton and Wirawan 1986, Suzuki 1984, 1986). Up to 12-15 years after the 1997-98 drought and fires, they relied heavily on pioneer species, mainly naturally regenerating native species, growing in areas that had been burned (Russon et al. 2015). Researchers who studied how they coped reported a relatively stable orangutan density and population size, with many known residents remaining in their pre-damage ranges (perhaps shifting or enlarging them somewhat), some believed to have moved elsewhere, and several infants born and surviving (OKP unpublished). Flexibility in diet and foraging habits, including an ability to rely on pioneer species and switch rapidly between preferred and fallback foods, was likely key to these orangutans' survival (Campbell 1992, Leighton and Wirawan 1986).

The KNP orangutan population continues to face threats in the form of habitat conversion for industrial agriculture and resource extraction (mining), poaching, and conflict with local settlers (both legal and illegal). These threats have increased dramatically since the early 1980s and have proven very difficult to police and control. Conflict with people around KNP is an ongoing problem, with one orangutan killed during 2018 shot 130 times with an air rifle (Gill 2018, Mongabay 2018). Orangutans occasionally raid crops, especially in areas where intensive deforestation has taken place, and are often killed in the process (Meijaard et al. 2011). Hunting has been implicated as a major reason for population declines of orangutan in Borneo (Voigt et al. 2018).

Table 1. Northeast Bornean orangutan have multiple traits that distinguish them from other orangutans. The following is a comparison of distinctive features of *P. p. morio* compared to *P. abelii* and *P.p. wumbii,* (the latter being the best studied orangutan taxa). Traits are summarized from van Schaik et al. (2009).

Dimension	Factor	***morio*** **trait**
Habitat	Forest productivity	Lower
	Impact of masting	Most?
	Large terrestrial predators (nb. tigers)	Absent
Morphology	Mandibles	Most robust
	Tooth enamel	Thicker
	Average brain size (cc)	Smallest
Behavioral ecology	Variation in fruit intake	Highest
	Reliance on non-fruit fallback foods	Most common
	Female home range size	Smallest
	Female day travel distance (m)	Shortest
	Ketones in urine (neg. energy balance)	Probably
	Sensitivity to logging	Lowest
	Population density	Among lowest
	Terrestrial travel	Common
Social organisation	Sociability	Lower
	Duration of consortships	Shorter
	Forced matings	Higher
	Susceptibility to social stress	Higher
Life history	Interbirth interval (mean years)	Shortest
	Reduced association with mother	Younger

Box 1: Orangutan Kutai Project

by Anne Russon

My research team started to develop our research project on wild orangutans in KNP in 2008, while conducting long-term research on orangutan rehabilitation and reintroduction of in East Kalimantan, Indonesia. Our Orangutan Kutai Project (OKP) was inspired by visits to KNP and the KNP office that indicated the park's habitat and its orangutans had recovered better than commonly believed from massive damage during the 1980s and 1990s. On the belief that both were essentially destroyed, researchers and conservationists who had worked with KNP and its orangutans in the 1970s and early 1980s had largely lost interest.

We considered that new research on KNP's orangutans would be valuable for several reasons:

- Since the Northeast Bornean orangutan (*P. p. morio*) was only recognised as a subspecies in the late 1990s, little was known about it. We aim to improve understanding of the special adaptations of the Northeast Bornean orangutan, especially those in East Kalimantan, which may differ from those in Sabah.
- To increase understanding of the nature of the habitat changes that KNP's orangutans have experienced, how well these orangutans have coped with these changes and how they have adjusted to them, as the basis for informing conservation efforts.
- KNP supports the last large protected population of Northeast Bornean orangutan in East Kalimantan, so improving understanding of their biology, behavior, and ecology (e.g. habitat qualities, needs, and usage; range and distribution of resources; ranging patterns; social structures) is important for informing effective conservation efforts.

We selected a research area (~5 km²) along the northern boundary of KNP, based on several field surveys indicating good forest cover and strong orangutan presence. Our research area overlaps with areas where orangutans were studied in the 1970s and 1980s, when the forest was near pristine, giving us the opportunity to assess changes in the habitat and resident orangutans' habitat use associated with the 1982-83 and 1997-98 forest fire damage and natural forest recovery since then.

Based on our first three years of field data (2010-12), we were able to show "good" recovery in the sense that: orangutans were abundant in our research area, healthy, and apparently reproducing normally; the area's forest area has recovered rapidly in terms of forest cover and now provides a good range of orangutan plant food species (climax and pioneer); these orangutans behave much as they did when the forest was near-pristine (i.e., similar home range size, day travel distance, activity budgets, food preferences and usage); and their travel data helped us identify 'key' species, i.e., species important enough to be destinations for foraging. We also developed a substantial list of orangutan food species, monthly phenological data for major tree species, and continuous weather records (daily rainfall, temperature).

We are now concentrating on longer-term patterns in KNP orangutans' feeding ecology and adaptations. KNP, as part of East Borneo, experiences the most severe effects of the El Niño Southern Oscillation (ENSO), including the most prolonged droughts during El Niño events and very heavy rainfall during La Niña events, and these swings in ecological conditions must certainly affect resident wildlife. Our data now span one complete ENSO cycle (2010-16), and indicate substantial changes in these orangutans' feeding ecology, behavior, and reproduction linked to this cycle. Several patterns are emerging: (i) orangutans changed their habitat use from year to year within the 2010-16 ENSO cycle, probably in search of good food supplies; (ii) their shifts in habitat use imply that an individual's 'home range' is much larger than previous estimates based on 1-2 years' data, (iii) female orangutans' interbirth intervals are very closely tied to ENSO events because they affect food supplies which in turn affect female fertility; and (iv) probably for this reason, KNP's adult female orangutans often support two offspring at a time (known as "offspring stacking") – a new infant plus a juvenile – although only one elsewhere.

Our project, including our research findings on orangutan behavior, biology, and ecology, also focuses importantly on orangutan conservation. Our long-term "home range" finding, for example, suggests KNP's carrying capacity for orangutans may be lower than commonly believed (i.e., one orangutan needs more habitat than short-term estimates suggest). Our data on KNP orangutans' food species have contributed to forest rehabilitation and restoration projects by identifying species most likely to benefit orangutans in East Kalimantan. We are working to formalize a cooperation agreement with the KNP office to undertake conservation work (forest enrichment) in addition to orangutan research. Finally, our project has contributed to several important international meetings organized with the KNP office.

Box 2: IUCN conservation status assessment of Northeast Bornean Orangutan

from (Ancrenaz et al. 2016a)

Fewer than 20,000 Northeast Bornean orangutans remain, mostly in Sabah and East Kalimantan, with a few scattered groups in North Kalimantan.

In Sabah, genetic evidence shows that more than 90% of the original orangutan population was lost over the past 200 years due to human activities (Goossens et al. 2006). With 39.5% forest loss in a 40-year period (1973-2010), the State has experienced the highest rate of forest loss in Borneo (Gaveau et al. 2014). Most of this loss has occurred in the eastern lowland forests that used to be the preferred orangutan habitat. Although about 80% of orangutans are currently found in protected forests, many populations are still declining because of further land conversion, killing and forest fragmentation. A new study estimates that in the past 10 years alone, the total number of orangutans in the State has declined by about 25% (Santika et al. 2017).

Populations in Kalimantan have suffered a similar fate due a combination of (illegal) hunting pressure, forest fires and forest conversion to agriculture. Models of perceived population trends for this subspecies in Kalimantan predict orangutan declines and local extinctions in the next 10 years (Abram et al. 2015). Indeed, in most of the areas of East Kalimantan occupied by orangutans, risk of conflict is high and this is likely to reflect pressures caused by rapid natural land-cover conversion to plantations. This subspecies is declining fast, and the combined impacts of climate and land-use changes are expected to result in further rapid loss of suitable habitat (Struebig et al. 2015). Fires compound the declines: for example, 90% of KNP was lost to massive fires in 1983 and 1998 and its orangutan population was reduced from about 4,000 individuals in the 1970s (Rijksen and Meijaard 1999) to a mere 600 (Wich et al. 2008).*

In summary, more than 86% of individuals in this subspecies will be lost in three generations (1950-2025) hence this subspecies is listed as Critically Endangered.

A young orangutan considers the fruit of a *Macaranga gigantea* at Prevab, KNP

Adult male orangutan at Samboja Lestari

* Estimate was not based on any ground surveys: the 600 appears to be based on estimates of remaining ‘good’ habitat in KNP at the time (~600 km2) * ‘low’ orangutan density estimate (1 individual/km^2).

Threats to the forests in and around Kutai National Park

Overview: threats to Borneo's rainforests

The native forests of Borneo have been impacted by logging, fire, and conversion to plantations and industrial-scale extractive industries that have increased at unprecedented scales since the early 1970s (Gaveau et al. 2014). The highest losses for Borneo were recorded in Sabah and Kalimantan with 39.5% and 30.7% of their respective total forest areas lost between 1973 and 2010 (Gaveau et al. 2014). Protecting forests from fire and conversion to plantations and other commercial industries is an urgent priority for reducing rates of deforestation in Borneo. In Kalimantan, most remaining forests in industrial concessions are found within logging concessions (~7Mha; ~57.1% of remaining forests in industrial concessions considered), followed by mixed concessions (~2.2Mha; ~18.4%), and oil palm plantation concessions (~1.2Mha; ~9.9%) according to Abood et al. (2015). Given that patterns of deforestation in Kalimantan are highly related to distance from the edge of the previous frontier of forest loss, high rates of forest loss were predicted and observed for the 2010-2020 period (Cushman et al. 2017). Combined with high levels of deforestation in close proximity to KNP (Figure 2), the park's forests are at high risk of exploitation.

Table 2. Area of industrial concessions in Indonesian Borneo (Kalimantan) as of 2010 (Abood et al. 2015) in millions of hectares (ha)

Area (million ha)	Oilp palm	Logging	Wood fibre/pulp	Mining	Mixed concessions	All industries
53,6	8,4	9,2	4,2	2,5	4,7	29,1

Burnt forest in the Mawas region. Fires are devastating to rainforests and a major threat to KNP.

Figure 2. Landcover change in and around KNP comparing the periods 1991 and 2016. The park boundary is indicated in yellow. Pale areas are associated with forest loss, with cloud cover over KNP in the 1991 image. The massive recent loss of forest is due to a range of human activities. Images © 2018 Landsat / Copernicus. Map Data © 2018 Google. Imagery date: 12/1991, 12/2016

Climate change

Historical climate

Borneo has a tropical climate, with historical annual averages of 22.9°C in temperature and 2,646 mm in rainfall (climate-data.org) though there is considerable variation across the island. In general, West Kalimantan receives more rainfall than East Kalimantan (Qian et al. 2013). While rainfall in more equatorial parts of Borneo is aseasonal, at KNP rainfall is seasonally distributed, with a rainy season from December to March (Figure 3). The loss of forest in Borneo has increased local daily temperatures and temperature extremes, and reduced daily precipitation (McAlpine et al. 2018). Inter-annual patterns are strongly influenced by ENSO events that currently recur at 5-7 year intervals on average (Ropelewski and Halpert 1996). These are the result of the interaction between atmosphere and ocean conditions in the tropical belt of the Pacific Ocean, and lead to altered global weather and climate patterns. Effects vary across Borneo and are most extreme in eastern Borneo, where wind speeds are higher and rainfall is significantly lower during El Niño years for the December to February rainy season period (Qian et al. 2013). By contrast, during La Niña events, sea surface temperatures in these regions become colder than normal, with higher than average rainfall in eastern Borneo.

Climate change - background

Since the industrial revolution of the late 18th century, humans have burned increasing amounts of fossil fuels such as coal, oil and gas, thereby releasing large amounts of carbon dioxide and other greenhouse gases into the atmosphere. The resulting greenhouse effect has led to a global average temperature increase of ~1°C, with local warming greatly exceeding this in some areas such as the Arctic (IPCC 2013). Such levels of warming have already resulted in a wide range of changes in components of the Earth's climate system (Garcia et al. 2014). These include increases in the magnitude and frequency of extreme weather events such as droughts, floods and storms, and secondary impacts, such as an increase of conditions conducive to wild-fires (IPCC 2013). Of special concern in Borneo are climate changes due to forest loss as global vegetation and climate are linked in both directions: when climate changes, so will vegetation, and when vegetation changes, so will the climate (Sheil 2018).

These changes are having far-reaching impacts on biodiversity. Most ecological processes, including in terrestrial, freshwater, and marine ecosystems, now show responses to climate change. These are occurring at levels from genes to individuals, populations, species and ecosystems (Scheffers et al. 2016). Observed changes in physiology, morphology and phenology are now widespread globally, and species are shifting their distributions, typically towards higher latitudes and elevations (Scheffers et al. 2016). Implications of these changes for people include unpredictable fisheries and crop yields, loss of genetic diversity in wild crop varieties, and increasing impacts of pests and diseases (Scheffers et al. 2016). While climatic changes improve survival for some species, for many more, the magnitude and rate of change have negative fitness consequences, leading to local or even global extinctions (Foden and Young 2016). Other anthropogenic pressures such as habitat loss and overharvesting are likely to act synergistically with climate change, in turn, greatly exacerbating negative impacts on many species, ecosystems and local livelihoods and economies.

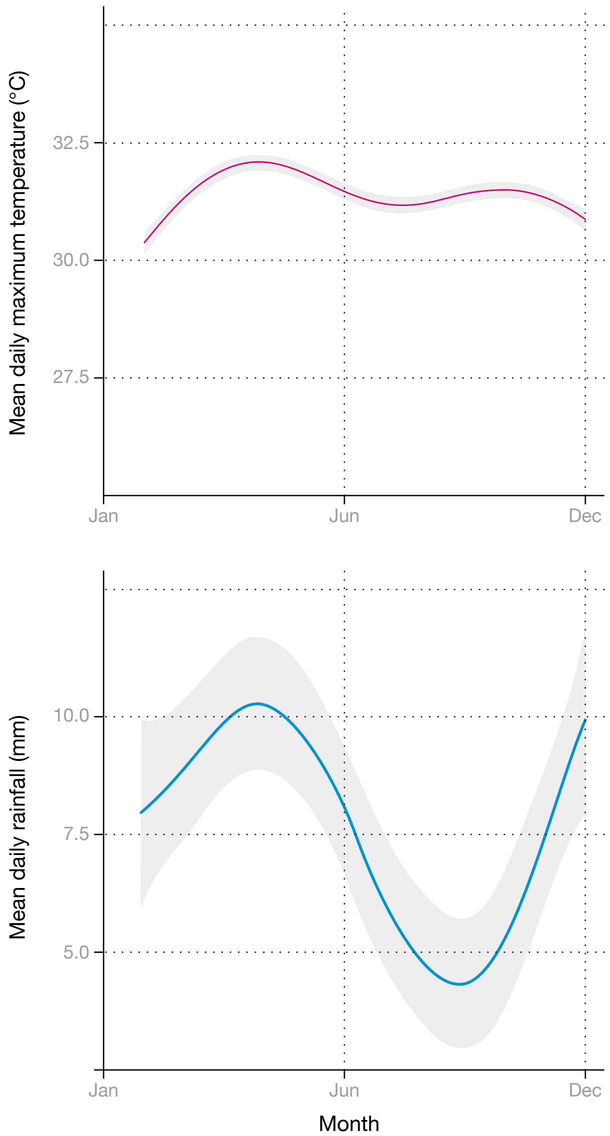


Figure 3. Mean maximum daily temperature and mean daily rainfall for each month in KNP, averaged for the period 2010-2016. The blue trend-line was calculated using a loess smoother function, and grey shading indicates the 95% confidence interval. Data are from Bendili (Mentoko area), KNP, courtesy of the Orangutan Kutai Project.

Observed climate changes

A recent analysis of temperature trends across Indonesia over the last three decades has revealed significant and spatially coherent trends of warming (Supari et al. 2017). The authors found that the frequency of cool days and cool nights has decreased whereas warm days and warm nights were observed more frequently (Supari et al. 2017). McAlpine et al. (2018) explored annually averaged daily mean temperature for Borneo between 1961 and 2007 and found that they increased at an average of 0.083°C per year, with a reduced, but still significant, increase of 0.009°C per year found when El Niño periods were excluded. Looking at these changes across different catchments indicated that greater changes tended to occur where forest losses had been more severe. The onset of observable climate change impacts on climate systems is widely regarded as beginning in the 1970s; the authors explored the change in trends before and after 1974 and found that mean daily temperature rose significantly faster after 1973 (Figure 4) compared to the 1961-1972 period.

Rainfall changes across Indonesia did not show a significant trend from 1981-2012 and were spatially incoherent, although a tendency towards wetter conditions was observed (Supari et al. 2017). These authors also found an increase in rainfall extremes, as measured by the annual highest daily amount and the rainfall amount contributed by extremely wet days. However, McAlpine et al (2018), examined Borneo's averaged mean daily precipitation and found that mean daily precipitation from 1951-1972 was 6.7mm per day, and showed little change beside inter-annual variability, but from 1973-2007, it declined by 0.04mm/yr (Figure 5a). These changes were attributed to land use and land cover change as greater decreases in rainfall were observed where forest loss was greater. Deforestation generates high albedo areas (e.g. bare lands), thereby inducing a reduction in precipitation because of reductions in evapotranspiration, convection, and horizontal atmospheric moisture inflow (Takahashi et al. 2017). This appears to be the case for eastern Borneo (McAlpine et al. 2018).

Rainfall records have been kept at KNP by the Orangutan Kutai Project since March 2010. We examined records from 2010-2016 and, in agreement with findings by MacAlpine et al. (2018), they show both a decrease in the number of rainfall days, as well as mean precipitation from daily rainfall events (Figure 5b). The trend clearly reflects the 2010-2016 ENSO cycle: the first two years (2010-2011 and 2011-2012) were very wet La Niña years; the middle two years ENSO-neutral (intermediate rain); while the end reflected the 2015-2016 El Niño drought, which was the driest period in Borneo since the 1997-1998 drought. While this data set is too short to derive any climatically meaningful trends, it helps to define the context of the current year's rainfall.

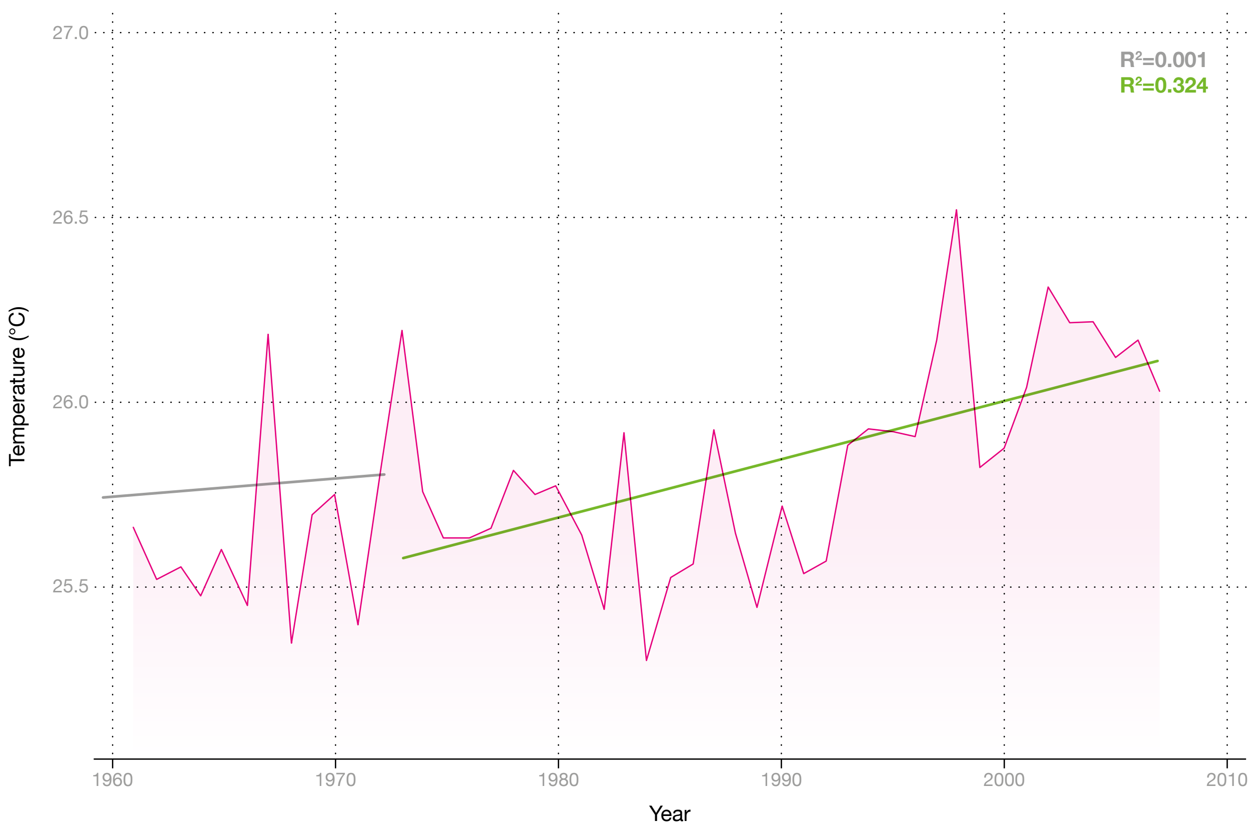


Figure 4. Changes in mean daily temperature across Borneo, comparing two time periods: 1961-1972 (i.e. before climate change began to affect climates globally) and 1973-2007 (i.e. as impacts became increasingly apparent world-wide) (McAlpine et al. 2018).

Projected future climate change

Globally, climate change predictions suggest warming temperature trends (IPCC 2013), and Southeast Asia is no exception. All models predict temperature increases in all areas of Southeast Asia, with the region's average temperature increase ranging between 1°C under a best case scenario and 4°C at worst by the end of the century (IPCC 2013) (Figure 6a and b). Borneo is amongst the areas projected to warm the most, and under a moderate climate change trajectory (RCP 4.5): projections of up to 2°C of change in June-August are anticipated by 2100 (IPCC 2013). Projections are generally consistent across models, leading to high confidence in the warming trends they predict.

In contrast to the certainty of temperature projections, global rainfall prediction models are highly uncertain and this is especially the case for Southeast Asia (McSweeney et al. 2013). Models predict a very slight wetting trend, but with projections ranging from slight wetting to a drying of 10mm per year under the trajectory associated with lowest and highest greenhouse gas emissions respectively (IPCC 2014) (Figure 7a and b). Borneo is projected to undergo a slight wetting in both October-March and April-September months, and under all time frames into the future (IPCC 2014). However, there is poor agreement between the models, leading to poor reliability of these predictions. McAlpine et al. (2018) show that drying trends are most extreme over southeastern Borneo, associated with high forest loss. Irrespective of total rainfall changes projected, increased temperatures will lead to greater evapotranspiration, leaving less water available for vegetation recovery (Corlett 2016).

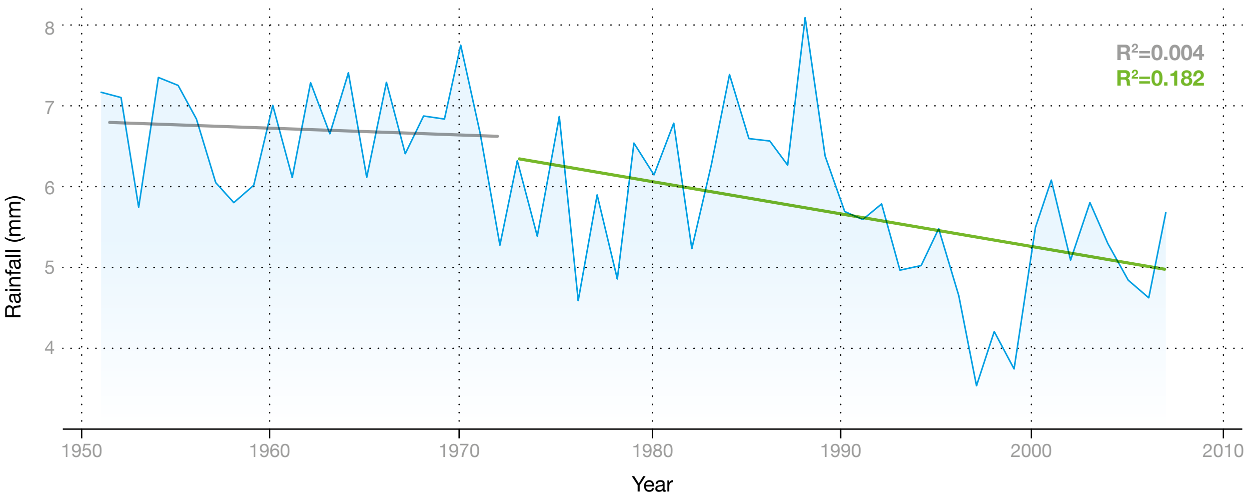


Figure 5 A. Observed changes in precipitation in the focal region: a) shows changes in mean daily temperature comparing two time periods; 1961-1972 (grey line; i.e. before rapid forest loss started and climate change began to affect climates globally) and 1973-2007 (red; i.e. as impacts became increasingly apparent world-wide) (McAlpine et al. 2018).

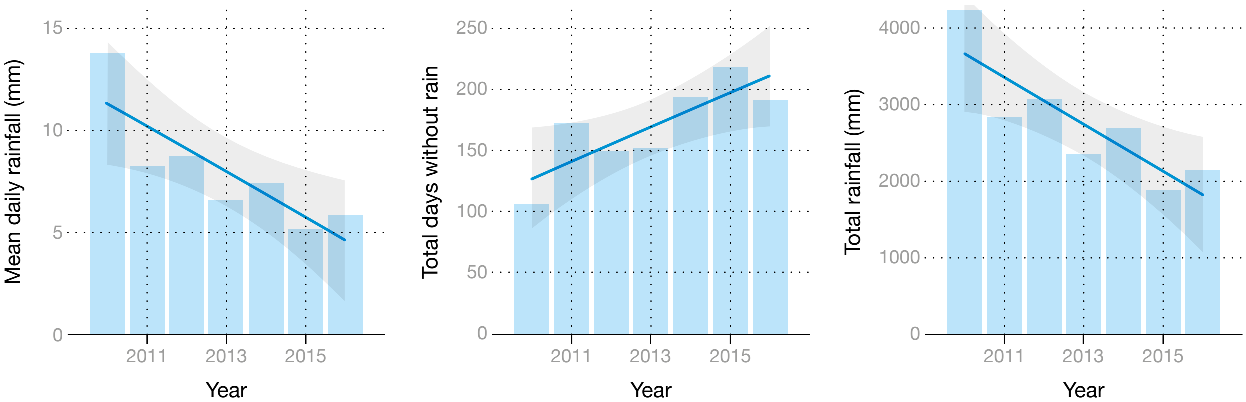


Figure 5 B. The 2010-2016 rainfall patterns from Bendili (Mentoko area), KNP, reflect the ENSO transition from La Nina wet years (2010-2011) to El Niño drought (2015-2016). Data courtesy of the Orangutan Kutai Project. Blue lines are regression lines, with the standard error of the slope represented as grey shading; however future trends are unlikely linear, as the data captures only part of an ENSO cycle.

Predictions of increased rainfall variability and extreme events are made with confidence (IPCC 2014). Increases in extreme storms and rainfall events pose a threat to forest integrity via high wind speeds, flooding and mudslides. More concerning, however, are increases in the intervals between rainfall events, and many models suggest that drought frequency and intensity will increase over the remainder of this century in some tropical forest areas (Chadwick et al. 2016). Drought and fire are an especially destructive combination as droughts tend to kill large canopy trees while fires kill smaller understorey stems. Fires have the potential to convert Borneo's forest cover to open vegetation over large scales (Garrity et al. 1996, Langner and Siegert 2009), which in turn has impacts on climate change.

Spatial models point to the possibility that a large amount of current orangutan habitat will become unsuitable because of changes in climate (Struebig et al. 2015). Across all climate and land-cover change projections assessed, models predicted that only 49,000-83,000 km² of orangutan habitat will remain by 2080, reflecting a loss of 69-81% since 2010. This projection represents a three- to five-fold greater decline in habitat than that anticipated from deforestation (Ancrenaz et al. 2016a).

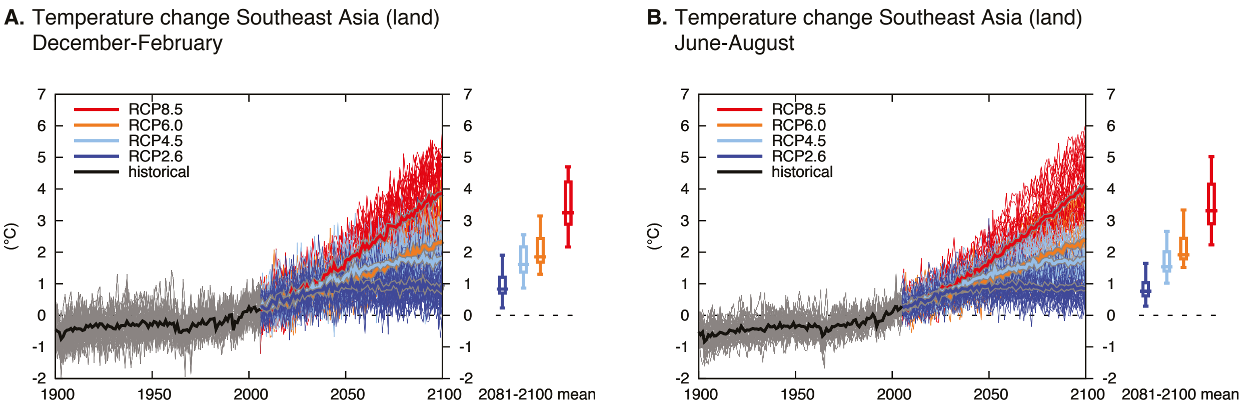


Figure 6. Projected changes in temperature in Southeast Asia (IPCC 2013): a) and b) show time series of temperature change to 2100 relative to 1986-2005 averaged over land for December-February and June-August, respectively. The colours refer to four Representative Concentration Pathways (RCP) of future greenhouse gas emissions, with RCP 8.5 representing highest emissions. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2081-2100 in the four RCP scenarios.

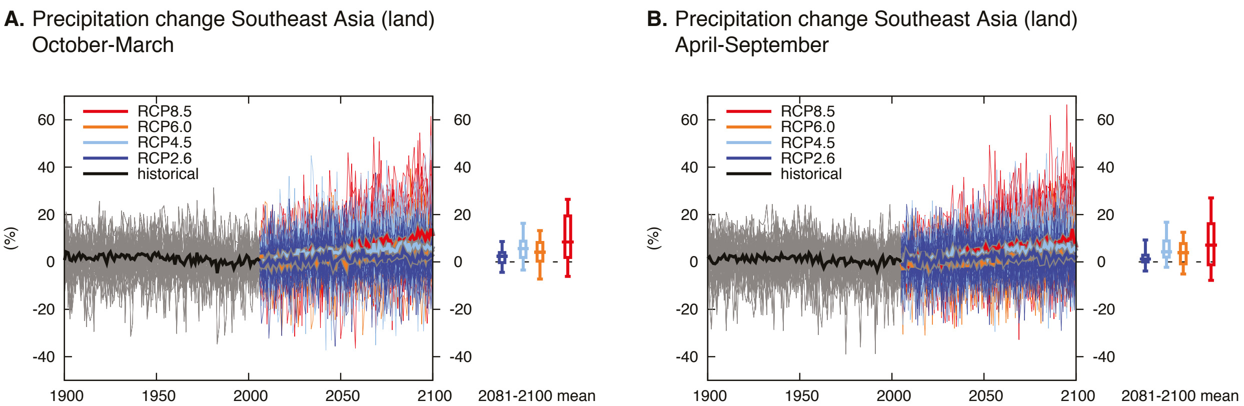


Figure 7. Projected future precipitation changes (%) in Southeast Asia (IPCC 2013): a) and b) show time series of precipitation change to 2100 relative to 1986-2005 averaged over land for October-March and April-September respectively. The colours refer to four Representative Concentration Pathways of future greenhouse gas emissions, with RCP 8.5 representing highest emissions.

Fire

Fires in Borneo were rare until recently (Goldammer 2007). Globally, fire weather seasons have lengthened across 25.3% of the Earth's vegetated surface since 1979, resulting in an 18.7% increase in global mean fire weather season length (Jolly et al. 2015). There has also been a doubling of global burnable area affected by long fire weather seasons and increased global frequency of long fire weather seasons (Figure 8).

Fire poses the greatest threat to KNP as a single catastrophic event. Fires are associated with ENSO caused droughts and human presence surrounding the park. Fire poses a major threat to the integrity of all Borneo's forests (Nelleman et al. 2007), largely driven by land conversion and drought, and drought is in turn strongly linked to El Niño events (Sloan et al. 2017). Most fires in Kalimantan are started by humans (Dennis et al. 2005). Three million ha of forest burned during the 1982-83 El Niño, and 6 million ha of forest burned during the 1997-98 El Niño. KNP was largely burnt both times, but most core areas escaped during the 2015-16 El Niño.

Depending on the intensity, fire can kill virtually all seedlings, sprouts, lianas and young trees because they are not protected by thick bark. Bark thickness in almost all tropical tree species increases with stem size, so that large individuals are much more likely to survive fire than small ones. A study in Sungai Wain (East Kalimantan) following the fires in 1998 found that regardless of the species, fire caused near complete mortality for trees with stem diameters less than 10 cm but scarcely increased mortality for individuals with diameters over 70 cm (van Nieuwstadt and Sheil 2005). One consequence of this pattern is that species well represented at large sizes are less impacted than species represented only by smaller stems, although palms are an exception, and seem to survive fire (van Nieuwstadt and Sheil 2005). The most important tree family in Borneo, the Dipterocarpaceae, is adversely affected by fire due to its thin bark, flammable resin, and a lack of resprouting capability (Whitmore 1992). However, some dipterocarps can regenerate in lightly burnt areas (Leighton and Wirawan 1986).

The 1982-83 fires in KNP resulted in widespread reptilian and amphibian mortality (MacKinnon et al. 1996). Fruit-eating birds such as hornbills declined dramatically and only insectivorous birds, such as woodpeckers were common due to an abundance of wood-eating insects. However, some species, including large herbivores, benefit from the new grass that flourishes after fire. As such, in East Kalimantan, local Kenyah and Kayan people regularly burn open areas to attract game, such as deer, muntjac, and Banteng (Hedges and Meijaard 1999). The degree of damage and fire intensity is related to previous logging intensity and residual debris on the forest floor (Leighton and Wirawan 1984, Mackie 1984). Fires increase the probability of burning in subsequent years (Meijaard et al. 2005). The most destructive fires occur in previously burnt forests (Cochrane and Schulze 1998). Many forests that burned in Borneo in 1982-83, or during the following El Niño droughts, burned for a second time in 1997-98 (Siegert et al. 2001). Repeated burns are a key factor in impoverishing biodiversity in rainforests. Fire breaks that involve sweeping the understory of debris would reduce danger of fires entering forests, but traditional fire breaks (zones cleared of all vegetation) would likely impose an impossible burden to maintain to any extent due to rapid vegetation recovery in tropical habitats.

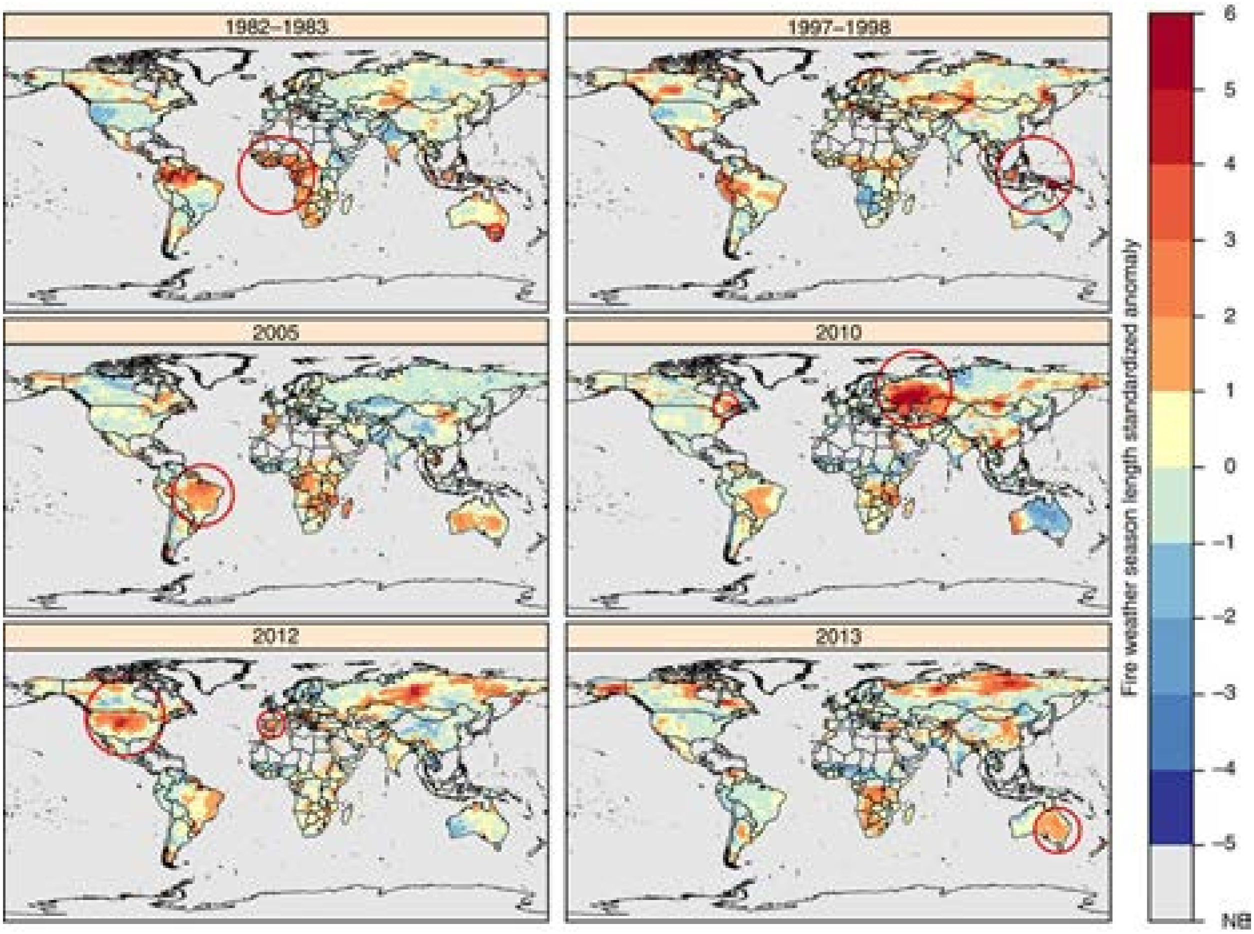


Figure 8. Fire weather season length standardized anomalies during significant global fire events. Red colours indicate areas where fire weather season anomalies are >1 s.d. from the mean (i.e. areas with longer seasons conducive to fire), while blue areas indicate shorter-than-normal fire weather season lengths. Areas with little or no burnable vegetation are shown in grey (NB). Red circles denote regions with significant fire activity during that time period: this includes Borneo and KNP for the 1997-1998 period. Source: Jolly et al. (2015)

Droughts

Droughts, defined as periods of 'abnormally dry weather long enough to cause a serious hydrological imbalance' (Stocker 2013), are distinguished from the annual dry periods that most tropical forests experience. Tropical droughts are often associated with multi-year climatic cycles and, therefore, inter-annual variation makes long-term trends hard to detect (García-García and Ummenhofer 2015). Natural droughts and rainfall exclusion experiments in tropical forests result in decreased tree growth and increased mortality (Bonal et al. 2016, Phillips et al. 2010, Rowland et al. 2015). Drought responses at the community level and above include changes in species composition and, where humans are present, interactions between droughts, forest fragmentation, and fire (Corlett 2016). Droughts, particularly with increased severity and frequency resulting from climate change, thus pose a threat to forest integrity and orangutans of KNP.

Invasive plant species

The presence and threat of alien invasive plant species frequently receives attention in relation to restoration work (Daehler 2003). According to Corlett (2010), alien invasive species are not yet a major conservation problem in tropical East Asia, except on remote islands, but their dominance on disturbed sites may slow or prevent recovery of native plant taxa. Since strict quarantine is impractical, management efforts should focus on early recognition and immediate control of potential problem species (Corlett 2010). Exotic climber species like bitter vine (*Mikania micrantha*), which can blanket open areas, are already a significant problem in Indonesia (Leung et al. 2009, Meijaard et al. 2005). *Clidemia hirta*, which originates from the Americas, is another highly invasive bird-dispersed shrub found in forests throughout the Paleotropics, including Indonesian Borneo; it invades forest openings, especially where the soil has been disturbed (Teo et al. 2003) and grows in KNP and other orangutan habitat in Borneo. The neotropical tree *Piper aduncum* is already a problem species in Indonesia and is known to be spreading in the forests of East Kalimantan (Padmanaba and Sheil 2014). Many widely planted genera, such as *Psidium* spp., *Passiflora* spp. and *Leucaena* spp. include species known to be invasive in some regions of the world. Such species can be found in natural closed forest, but they are generally favoured by disturbance (Cronk and Fuller 2014, Moles et al. 2012, Osunkoya et al. 2005). Native species such as ferns or alang-alang grass (*Imperata cylindrica*) can be equally problematic in disturbed areas where restoration activities occur (see case studies below).

A timber mill processes trees illegally harvested near Mantangai, Mawas

Roads, settlers and encroachment

The settlement of lands along the road between Bontang and Sangatta currently pose the biggest ongoing threat to the integrity of KNP. The road connecting Bontang and Sangatta was completed in 1991. Bontang (current population ~150,000) was then a minor fishing village until the establishment of a fertilizer company and oil refinery. The town was originally within KNP. Sangatta was at most a minor community on the Sangatta River 40 years ago, but is now the seat of the regional (Kabupaten) Kutai Timur government and has a population of ~100,000.

Lands adjacent to the Bontang-Sangatta road have since been colonised by a variety of people, many of them Bugis from Sulawesi, seeking livelihood opportunities (Vayda and Sahur 1996). The presence of coal in and around the park, coupled with mixed messages on the status of the park by previous governors has led to widespread illegal settlement: recently, annual population increase in what is now referred to as the 'special zone' of KNP is 22%, with a major proportion of people (45%) hoping for declaration of an enclave within the park (Sawitri and Adalina 2016). In the meantime, there is ongoing use of the park's resources, mostly illegally, according to KNP authorities.

Roads facilitate access, illegal activities and settlement. Here, drainage canals were created through sensitive peat areas in Central Kalimantan.

Illegal resource extraction (e.g. for timber) has for some periods been a major source of income for settlers (Limberg et al. 2009). Illegal hunting and mining are also of concern but are as yet poorly quantified (TNK 2016). Although it is illegal, land in KNP is bought and sold (Limberg et al. 2009). While greater law enforcement is certainly required to deal with this situation, the national park authorities have also recognised the importance of engagement with the community, and as such have allocated resources to community engagement as of 2018. In the meantime, slash and burn agriculture continues to encroach toward the core zone of the park (Figure 9). The use of fire in agricultural practices poses a great threat to forest integrity due to the risk of spreading into the national park, especially under the warmer and drier climatic conditions expected due to climate change.

Fertiliser factory bordering mangrove forests, Bontang

Mining

The rapid growth of Sangatta town can be attributed to the establishment of the Sangatta coal mine on the edge of KNP, which started operating in 1991. The mine is operated by Kaltim Prima Coal (KPC), which is owned by PT BUMI Resources Tbk. Bumi was awarded 'Indonesia's Most Powerful Companies Award' in 2017 (PT Bumi Resources 2017).

KPC is the largest export coal mine in the world, with coal sales mostly to Indonesia (37%), India (29%), Japan (11%) and China (9%) (PT Bumi Resources 2017). Coal and mineral extraction (notably gold, diamonds and other gemstones in Borneo) is a major source of employment and economic revenue. In 2016, the mining industry contributed approximately 4.2% to Indonesian Gross Domestic Product (Bank Indonesia in PWC 2017). Environmentally sustainable mining is a challenging exercise: open cast mining has been described as devastating to forest integrity, biodiversity and food production in the short-term (Goodland et al. 2009).

In Indonesia, mining concessions are now obliged to implement reforestation strategies in areas where mining has been completed and biodiversity offsets are also being explored. The environmental law was updated in 2009 by Law No. 32/2009 ("Environmental Law"). It requires the Central Government and Regional Governments to prepare a strategic environmental analysis and ensure that the principles of sustainable development have been integrated into the development of a particular region (PWC 2017). Together, both the Mining Law and the Environmental Law require mining companies exploiting natural resources that have an environmental or social impact to create and maintain an environmental impact planning document (Analisis Mengenai Dampak Lingkungan or AMDAL). This document consists of an environmental impact assessment, an environmental management plan and an environmental monitoring plan. The sanctions applied for breaches of the Environmental Law range from three to 15 years of imprisonment and/or a fine from Rp 100 million (USD 7,000) to Rp 750 million (USD 53,000) (PWC 2017).

Coal production at KPC was around 62 million tonnes in 2017, with reserves of just under 1 billion tonnes on 90,938 ha of concession (PT Bumi Resources 2017). Given current rates of production, this implies an estimated 15-20 further operational years at Sangatta. The concern among park authorities is that there will likely be a very powerful lobby seeking exploitation of the coal within the national park towards the end of the operational period of the current mine. Currently KPC undertakes reclamation of mined land for which they operate an in-house nursery of selected plants. During 2016, KPC revegetated 929 ha, for a total rehabilitated area of 1,118 ha.

Currently, post-mining community empowerment programs carried out by KPC include agricultural pilot programs (cattle, poultry, fish, tapioca, soya and corn), enterprise development (local Dayak crafts and clothes), tourism education and ecotourism (KPC Sustainability Report 2016). For the latter, 200 ha of reclaimed mining area Telaga Batu Arang (TBA) has been set up as a 'community-based nature attraction', which is in the buffer zone of KNP. KPC also assisted in the formation of six Tourism Awareness Groups (Pokdarwis) in Sekerat, Sangkulirang, Sandaran and Karangan villages that have tourism potential in the form of beaches, islands, and sea and karst caves, as well as natural hot spring baths (KPC Sustainability Report 2016). As of yet, no tourism initiatives currently involve either orangutan conservation or KNP, both of which should be of priority for KPC given the stated Environmental Preservation mandate of KPC, as stated below:

"3.1. Preserving Orangutan Populations in Reclamation Area

Orangutan is one of the protected and endemic fauna in our country, Indonesia. The island of Kalimantan, especially East Kalimantan, where KPC's operations is located, is one of the natural habitat of Orangutans. To that end, one of the main objectives of reclamation and biodiversity conservation program KPC is to preserve the habitat and population of Orangutans in our reclamation area."

Source: http://www.kpc.co.id/sustainabilities/environment?locale=en accessed 21 February 2018.

On the southern boundary of KNP is the open cast coal mine operated by PT. Indominco Mandiri, established in 1988. Its two concession areas total 25,121 hectares, but its reserves and production are much lower compared to KPC's: 75 million tonnes of reserves as of 2015 (http://www.itmg.co.id/operation/resources-reserves), with production in 2016 at 25 million tons across multiple mining sites. Like KPC, Indominco has an in-house nursery (with an 800,000 plant capacity) for on-site reclamation. As Indominco is subject to different land laws than KPC, it is also obliged to undertake additional reforestation. To this end it has been granted 18,000 ha of restoration concessions inside KNP. To date, enrichment planting has been conducted in 6,000 ha of Indominco's reforestation concessions on the southern side of KNP. This relationship has been useful to KNP, because Indominco has conducted biodiversity inventories in partnership with Mulawarman University. However, according to mining and national park spokespeople, restoration activities here have faced challenges including unavailability of most indigenous species of choice and an ambiguity surrounding what constitutes 'success', as government regulations for restoration differ with respect to their requirements for mining companies versus for national parks.

A more in depth analysis of the situation with respect to mining and orangutan around Kutai National Park can be read here: https://news.mongabay.com/2014/10/coal-climate-and-orangutans-indonesias-quandary/

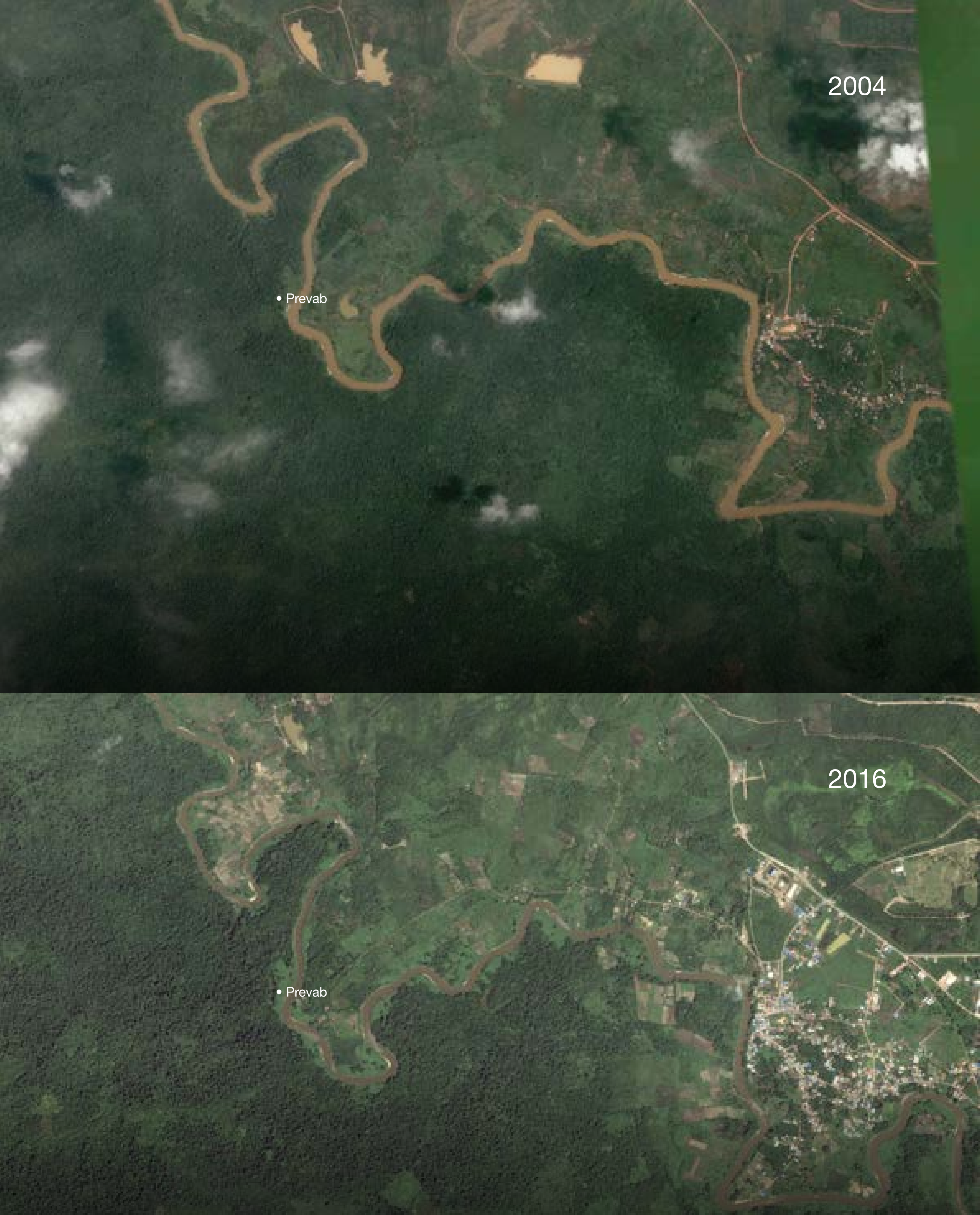


Figure 9. An aerial comparison of the forests around Prevab ranger and research station on the Sangatta River for the periods 2004 and 2016. Forest (dark cover) has disappeared east of the river by 2004, and is disappearing south of the Prevab station well within the park boundaries in 2016. This situation extends down much of the Bontang-Sangatta road, up to 5 km from the main road. Image © 2018 Digital Globe. Map Data © 2018 Google. Imagery date: 2/2004, 12/2016

Oil-palm industry

While oil-palm plantations superficially resemble forested areas, there are innumerable studies that indicate for most taxonomic groups, palm plantations are biologically depauperate compared to primary forest (Brühl and Eltz 2010, Edwards et al. 2010, Fitzherbert et al. 2008). Borneo is the world's largest palm oil producing region, with 8.3 million ha of industrial oil palm plantations as of 2016 (Gaveau et al. 2016). Indonesia is the world's largest producer of palm oil, producing more than 20.9 million tonnes annually (Crutchfield 2007) with production set to double by the end of 2030 (Gilbert 2012). The oil palm industry is the leading cause of deforestation and highest source of carbon dioxide emissions in Kalimantan (~0.7-1.4 Mt CO_2) (Abood et al. (2015).

The south side of KNP is flanked by an industrial plantation of oil-palm. While there is no immediate threat to forest integrity of the park from this plantation, the planting of oil-palm by settlers in the park is a concern. Neither of the previously published studies on the settler communities mentioned oil-palm as either an important crop (Vayda and Sahur 1996), or as economically important (Limberg et al. 2009), and the importance of this crop to local people remains unclear. The planting of oil-palms in and around KNP will likely also lead to more orangutan-human conflict, as orangutan have been recorded eating the fruit in plantations (Ancrenaz et al. 2015).

Experts believe smallholder planting of oil-palms may be linked to a significant amount of deforestation (IUCN in prep) as Indonesian smallholders manage about 22% of all Indonesian plantations by area, but little research exists on who these different growers are, and what impact they are having on biodiversity. Growers typically avoid licensing rules by keeping each plantation below a 25 hectare threshold. Investigation is required to see if this situation is occurring in KNP. Oil has to be extacted within little more than a day at most to get a valuable product and this processing is generally in large factories. Consequently, smallholders have to live near an oil mill in order to get good prices. This means even the most remote small holders need to bring their crop to a central point for collection, and this can be monitored (Sheil et al. 2009).

Large companies sourcing palm oil are under pressure to do so from 'sustainable' plantations by national and international consumer and government programs. Various conservation initiatives are promoting biodiversity offsets to reduce overall forest loss and biodiversity loss. These include land-sparing and land-sharing initiatives. In land-sharing initiatives, potential exists for reforestation efforts that attempt to restore elements of natural forests. These initiatives can be informed by improved guidance on reforestation practices, including in their considerations of biodiversity, orangutan conservation, ecological function and climate change.

Oil palm plantation in the Mawas region, Central Kalimantan

Reforestation / Restoration

Where extensive land clearing or degradation has already occurred, restoration is central to achieving species protection targets (De Groot et al. 2013). Ecological restoration is the process of assisting the recovery of a degraded ecosystem, including functions and components of the original biodiversity (Society for Ecological Restoration International Science & Policy Working Group 2004). Restoration activities can range from managing weeds and fire, to re-creating ecosystems from completely denuded landscapes (Chazdon 2008). Restoration is the cornerstone of many climate adaptation action plans (Shoo et al. 2013), but a key challenge remains regarding how to set objectives for restoration while giving consideration to climate change: under future climates, the historic ecosystem may not thrive, and predicting a new ecosystem suited to future conditions is highly uncertain. Therefore, traditional restoration practices may not be the best options (Reside et al. 2017).

*"**Rehabilitation** shares with restoration a fundamental focus on historical or pre-existing ecosystems as models or references, but the two activities differ in their goals and strategies. Rehabilitation emphasizes the reparation of ecosystem processes, productivity and services, whereas the goals of restoration also include the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure.*

*The term **reclamation**, as commonly used in the context of mined lands, has an even broader application than rehabilitation. The main objectives of reclamation include the stabilization of the terrain, assurance of public safety, aesthetic improvement, and usually a return of the land to what, within the regional context, is considered to be a useful purpose. **Revegetation**, which is normally a component of land reclamation, may entail the establishment of only one or few species. Relative to other kinds of activities, restoration generally requires more post-installation aftercare to satisfy all these criteria."* (Society for Ecological Restoration International Science & Policy Working Group 2004)

Areas which have been used to meet human needs, and are now in degraded states, offer opportunities for potential forest restoration projects. Doing so there is an opportunity to shape forests to be climate change resilient. Large scale conservation projects can contribute to a greening Earth with positive effects on carbon sequestration to mitigate climate change (Tong et al. 2018). Restoration projects have the potential to provide multiple benefits for humans, including through payment for Ecosystem-based Adaptation, and by restoring ecosystem services and hence the human health and well-being they support. However, working within intentionally human-degraded landscapes can be challenging and costly, and reforestation is by no means straightforward. In such cases, prior and informed consent, and local community engagement and involvement in the entire process are essential (Graham et al. 2017).

Techniques for forest restoration

Reforestation is ecologically, socially and logistically complex: long-term time commitments are required, both to safeguard initial investments, and to ensure protection, monitoring and management during a long interim period during which there will be few or no obvious returns on investments (Chazdon 2008). The ultimate goal of independently viable forests sustaining biodiversity at near pristine levels will be reached decades after the initial reforestation efforts. If the ground work to achieve a safe and sustainable reforestation environment can be completed, then species planted now also need to be suited to conditions decades into the future, which could be very different from those currently observed, both politically and climatically.

Assisted re-vegetation methods can include:
1. enrichment planting of native trees and
2. liberation cutting of competing vines, bamboos, herbaceous plants, or early successional trees which can be applied individually or together (Putz et al. 2001).

Previous studies have shown that these two methods make logged forests better carbon sinks and encourage more rapid forest regeneration (Wheeler et al. 2016). Some positive effects on the diversity and community composition of trees have been noted (Wheeler et al. 2016), as well as on understorey avian (Ansell et al. 2011) and invertebrate (Edwards et al. 2012) communities. However, others suggest there is a danger that these techniques cause further damage to logged forests, and are destructive carbon farming that will erode biological value (Putz and Redford 2009). After finding reduced phylogenetic diversity and functional avian group types in restored forests, Cosset and Edwards (2017) suggested it is important to focus restoration only on the most degraded areas or at reduced intensity.

Fast growing successional-forest species are good to use in early stages of reforestation efforts.

Degraded area reforestation is more challenging as consideration also needs to be given to recovery of soil microbes and organic matter (Bonner 2017).

Wills et al. (2017) suggest that planting trees in a cleared landscape provides conservation value in itself. In addition, Wills et al. (2017) recommend that if fewer species are used as less costly and technically simpler solutions for initiating recruitment, then wind-dispersed native species (e.g. species from the Dipterocarpaceae) in addition to other limited functional traits (e.g. large-seeded species) should be planted to enhance long-term survival of ecologically significant native tree populations. The dipterocarp forests of Southeast Asia are believed to be amongst the most promising for sustainable management (Meijaard et al. 2005). Efforts to maximise their potential have had mixed success from a sustainable timber production perspective as dipterocarps spend years as seedlings in the understorey and need protection from browsing animals and fire (Appanah and Turnbull 1998). Given the region's vulnerability to drought, consideration needs to be given to early stage management since drought periods decrease tree growth, survival, and recruitment, particularly during early succession (Uriarte et al. 2016). Reforestation of isolated patches in transformed landscapes without adjacent primary forest will likely be unsuccessful as isolation and fragmentation increases forests' vulnerability to fires, wind, and drought (Uriarte et al. 2016). The effects of temperature on forest recovery remain unexplored (Uriarte et al. 2016).

The following are **Basic Steps** to implement cost-effective and location-appropriate landscape restoration following Graham et al. (2017):

1. Know your location.
2. Choose appropriate re-vegetation methods based on natural regenerative ability.
3. Choose a wide range of species
4. Adopt seedling nursery best practice.
5. Plant into locations where primary regeneration barriers have been removed and trials have been conducted.
6. **Implement long-term care and monitoring.** This is a vital step: if this cannot be done, then it is likely the restoration project will fail. The issues leading to deforestation in the first place need to be addressed.

It should be noted that the primary purpose of this document is to aid selection of appropriate tree species for KNP. The above steps are illustrated with two case studies (Box 3 and Box 4).

Box 3: Restoration case study 1 - Mawas peat forests of Central Kalimantan

Setting:

Southeast Asia contains seventy percent of the world's total tropical peatland, with 25 million hectares of peat swamp forest in Indonesia now reduced to ~17 million ha (Aldhous 2004). The largest land conversion scheme was the Mega Rice Project in Central Kalimantan: established in 1996 by the former Indonesian President Suharto. Using a large investment of Indonesian Government funds, 4,600 km of drainage channels were excavated with the intention to develop landscape-scale rice production, making Indonesia self-sufficient in its rice needs. No environmental impact assessment was undertaken.

The Mega Rice Project, however, was not successful: productive rice was never grown there. Instead, large areas of forest were cut down, land was cleared, and an exceptionally severe El Niño climatic event in 1997 led to the severest forest and peatland fires ever known.

5,000 orangutan are believed to have died (Aldhous 2004). Between half a million and three million hectares of vegetation burned, much of it on peat, releasing an estimated 1 billion tonnes of carbon into the atmosphere. Now the landscape burns nearly every year, releasing poisonous smoke and hastening global warming.

Data sources: (Aldhous 2004, Page et al. 2002); Kalimantan's peatland disaster.

Reforestation efforts in the Mawas. Prolonged inundation can kill some species: site specific species are required.

The area is now a target for numerous restoration activities conducted by government and non-government organisations, including the Borneo Orangutan Survival Foundation (BOSF).

Know your location

Tropical peatland's natural state is forested, with highly efficient nutrient cycling. The water table is consistently high (near the peat surface year-round). Flooding is prevented through the peat dome's shape and water flow is slow due to the hummock and hollow topography. To protect the peat, the forest must be protected: the canopy creates a humid and cool microclimate that protects the peat while tree roots hold the peat in place and keep it aerated.

After the forest is gone from the surface the hummock and hollow peat structure is lost. As a result, water flows more quickly resulting in drier peat. Then oxidation and compaction increase, as do risks of fire and flooding. Prolonged or frequent disturbance makes forest regeneration increasingly unlikely and the peatland becomes dominated by ferns and shrubs.

Monitoring was conducted via satellite, and on the ground to measure water table depth (dipwells and staff gauges), seed dispersal (seed traps), natural regeneration and competition (vegetation plots), and physical and chemical soil properties (soil analysis). Sites for reforestation were then selected based on state of degradation and proximity to undisturbed forest. Blocking of drainage canals is a major activity to restore soil moisture levels.

Choose appropriate re-vegetation methods and species based on natural regenerative ability

A survey of the degraded area found species already growing there (*Shorea balangeran*, *Combretocarpus rotundatus*, *Alstonia* spp. and *Cratoxylon glaucum*), which were included as reforestation target species.

Local communities were involved in the restoration process from the initiation of the reforestation program in 2010. Village agreements were developed after prior and informed consent processes were met, which described responsibilities and expectations of both the program and the village participants, including the set-up and management of local community seedling nurseries. These were to be run autonomously by the participating community members in the form of private businesses. BOSF helped the communities set up the nurseries, and trained them in seedling, planting and post-planting care (2011-2012). Seedlings of agreed species could then be sold to the program for agreed prices, and the sellers could also obtain seedling planting and after-care work packages. These autonomous businesses continue to run, selling seedlings to BOSF and also to other restoration programs conducted by mining companies in the area (2013-to date).

Choose a wide range of re-vegetation species

Native species were chosen that provide a suite of characteristics to help the forest quickly recover e.g. large fruit species that bring seed dispersers back (*Garcinia* spp.), fast growing species (*S. balangeran*), species that close a canopy fast (*Campnosperma coriaceum*), are nutrient-fixing (*Koompassia malaccensis*), and are fire-tolerant (*Combretocarpus rotundatus*). Seeds were collected wherever possible, but wildlings were used for species hard to source as seeds (*S. balangeran*), or difficult to germinate (*C. rotundatus*).

Enrichment planting: weeding has been conducted and fertilizer applied.

Adopt seedling nursery best practice

Communities were trained in maintaining optimal nursery conditions. Practices found to be useful included:

- Providing 60-70% shade-roofing that is rain-permeable
- Raising the height of seedling trays (which reduces disease spread and physical damage)
- Planting media mixed with native soil for adaptation
- Protection from pests with netting, using fungicide as needed (an entire stock can be lost from rodents or infection)
- Regular weeding and root cutting (to remove competition and transplanting stress)
- Grade seedlings by age and health so condition is more easily monitored
- Acclimatise seedlings ahead of planting to reduce shock

Plant into locations where primary regeneration barriers have been removed, and trials have been conducted

Planting only occurred into areas where the primary regeneration barriers, such as flooding or fires, had been addressed. Only good quality seedlings are planted at a density of between 400-2,500 seedlings per ha (spacing 5 x 5 m to 2 x 2 m). Seedling planting density was decided based on logistics, budgets, and desired speed of canopy closure.

Implement long-term care and monitoring

One month after planting all seedlings were checked and any that had died were replaced. Weeding continued regularly until seedlings were at least 1 m tall, at which stage they were taller than the ferns that dominate most sites. Monitoring of the replanted areas should continue, ideally until the forest canopy is recovered. Local community members can be key in implementing this kind of long-term monitoring.

Enrichment planting: weeding and care is required to ensure survival, especially of slow growing species, highlighting the long term commitment required for successful restoration efforts.

Box 4: Restoration case study 2 - Samboja Lestari

The East Kalimantan Orangutan Reintroduction Program at Samboja Lestari was the first orangutan reintroduction program established by the Borneo Orangutan Survival Foundation in 1991, specifically to provide care and rehabilitation for displaced or orphaned orangutans. Samboja Lestari also has a model forest rehabilitation program consisting of about 2,000 ha of restored forest on what was grassland resulting from forest clearing and burning. Planting commenced in 2001, and most of the area now has a canopy. Management is ongoing.

Planting in lanes helps direct the management efforts of weeding and fire control.

An arboretum of about 50 tree species was established on the site as a reference set of species. Initially, pineapples and *Acacium mangium* were used at some sites in order to give short-term value to the land and create a canopy cover. Species selected for reforestation activities depend on the zone. Fire tolerant species were planted on the property's perimeter, as neighbouring land use is dominated by coal mining and agriculture, which can bring fire-associated risks. In areas that are utilized by the local community, multi-purpose tree species were planted. These include sugar palm, which provide fruit as well as palm leaves for thatching.

An on-site nursery provides the seedlings used in restoration. Plants are weeded, and fertilizers are applied. Certain threats (e.g. land invasion and fire) continue from outside the property perimeter. There is a fire tower and patrols attend situations as soon as they arise.

The arboretum at Samboja.
Reference species are clearly signposted.

Restoration activities in Kutai National Park

In East Kalimantan, reforestation is typically carried out following mining, but has also been used for conservation purposes, such as in and around KNP, to enrich or restore key forest areas. In the case of KNP, companies with corporate social responsibility requirements can approach the park in order to conduct restoration within the park's rehabilitation zone (Figure 10). After a candidate corporation or company has applied for a concession, an inventory is conducted of the proposed area for reforestation. There are three categories of reforestation, which depend on the number of stems per hectare at the restoration site: >700 stems/ha qualifies for protection only, 200-700 for 'enrichment', while <200 for rehabilitation restoration. Once permission is granted from the national Forestry authorities in Jakarta, all parties engage in technical planning. This includes decisions on which species to use (these must generally all be indigenous); a time schedule; a planting process; and a 3-year required maintenance plan. After three years the area becomes the responsibility of the national park.

Indonesia has set itself the target of reforestation on 100,000 ha by 2019. Of KNP's 64,017 ha rehabilitation zone, 32,306 ha have already been allocated to various companies as reforestation concessions as of the beginning of 2018. The largest portion, 18,600 ha, has been allocated to PT Indominco Mandiri, the coal mining company operating to the south of KNP. Of the 32,306 ha allocated, as of February 2018, KNP authorities reported that restoration has been completed for 16,525 ha or just over half.

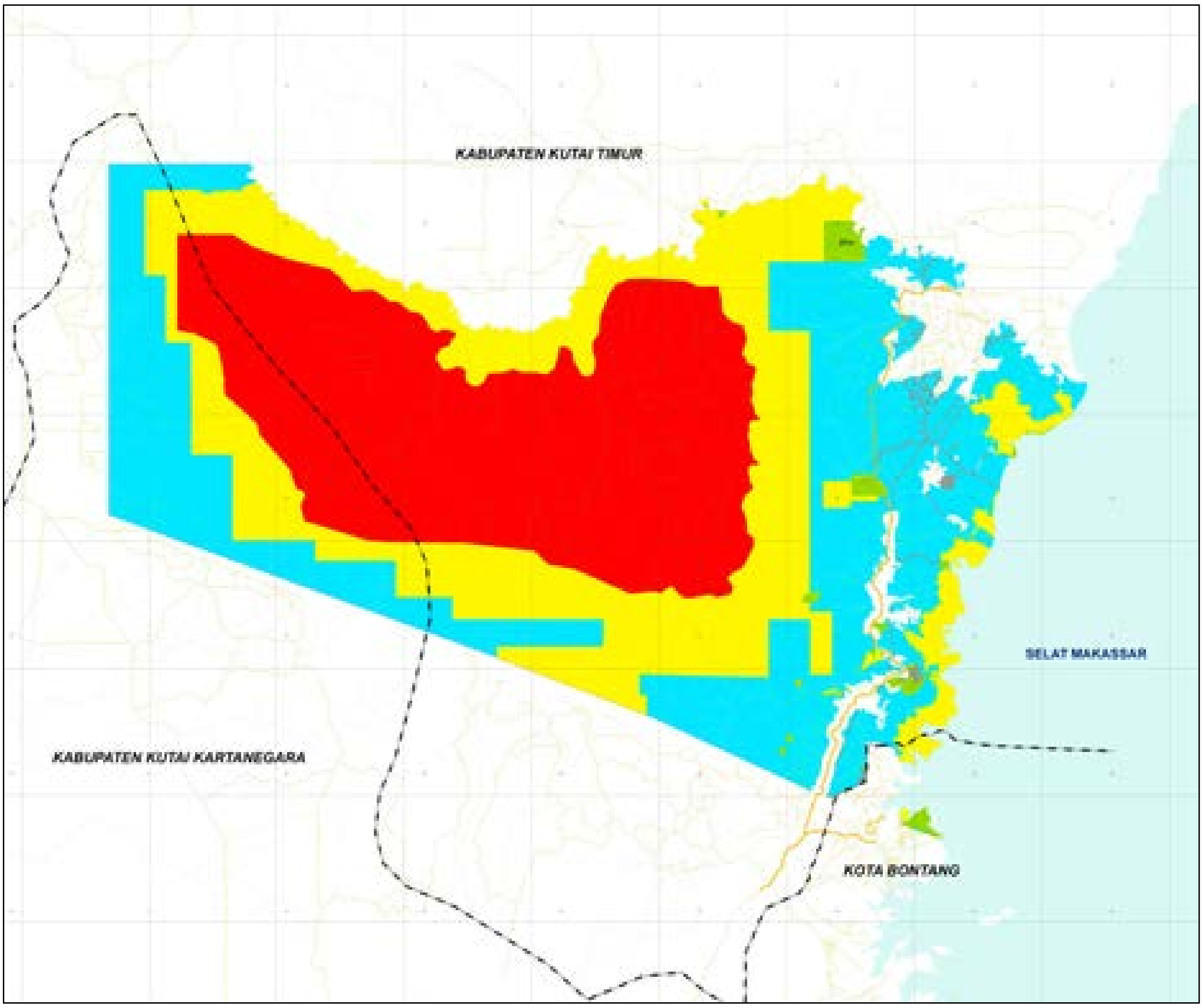


Figure 10. Map of Kutai National Park showing management zones (from TNK (2016). Red = "zona inti" (core zone); Yellow = 'Jungle' zone; green = 'utilization' zone; blue = Rehabilitation zone; grey = 'Special' zone.

Which species should be used for forest restoration in Kutai National Park?

Tree species selected for restoration projects may depend on the context of the area (buffer zone or the core zone); and the project's primary objectives (e.g. restoration to enhance food productivity for orangutans, restoration for climate change resilience or restoration of buffer areas where community use is expected). As a starting point, only indigenous tree species should be used for reforestation within KNP, of which there is a wide set of species to choose from.

Which tree and plant species occur in Kutai National Park?

KNP's records list 1,278 unique species in the checklist of plants of KNP (TNK 2016), representing 144 families, with several species only identified to genus, and 2 species only identified to family level. The most species rich families are illustrated in Figure 11, with the top three families being Rubiaceae (89 species), Dipterocarpaceae (76) and Annonaceae (67). Forty-four families (30.5%) are represented by only 1 species each. For reclamation or reforestation of severely degraded landscapes for which no prior inventories are available, it is recommended that all these families are represented in the set of species selected.

Selection process of plant species for the climate change vulnerability assessment

During 2016, a draft list of tree species to be considered for the study was constructed, firstly, using raw data on all plant species observed to have been consumed by orangutans (Russon et al. 2009) provided by the Orangutan Kutai Project. This was supplemented with comprehensive species lists from six long-term vegetation monitoring plots within the park maintained by the OKP. From this list, species were selected for assessment if they met one of the following two criteria, which aim to ensure that the most common and/or structurally important species of the park were included:

1. Encountered 10 or more times across all plots
2. Overall basal area of greater than 1 m^2/ha

The draft tree list was then circulated electronically to a group of experts consisting of various tropical rainforest ecologists and botanists who are familiar with the study region. The experts were asked to review the list and to suggest amendments, including any omitted species that are known to be important orangutan food plants, are structurally important species and/or considered as high importance for some other reason (e.g. system-regulating species). Staff at the UK's Royal Botanic Gardens, Kew, then compared the draft species list with the most up-to-date electronic taxonomic resources available, providing authority and synonym information for matches and consulting taxonomic experts to resolve problems where appropriate and feasible. Where taxonomy remained unclear, and where the name provided from the initial list could indicate two or more species, the species thought most likely to occur in the focal region (East Kalimantan, Borneo) was selected.

An assessment workshop was then held in Bontang, East Kalimantan from 8 May to 12 May 2017, involving ~30 botanical, orangutan, ecological and local experts. Here, additional plant species were added based on a species list obtained from the KPC nursery associated with reforestation efforts of their coal mine rehabilitation sites. The final list was 247 species after accounting for taxonomic issues. Although the list is dominated by tree species, it includes representatives of a variety of other plant growth forms, including shrubs, vines and lianas. This list is provided in Appendix 1.

Which species are of greatest importance as food sources for orangutans?

We ranked each of the focal species in this list in terms of its importance as an orangutan food source as follows: each species was scored firstly as being present in the diet of the orangutans of KNP (score 1), and then whether the species has been recorded in other dietary studies of orangutans (score 0.5). The sum of these values was then weighted to give the most important food plants of KNP a score of 2 (based on OKP research experience), generating a final score ranging from 0-2, with 0 unimportant and 2 very important. 129 species of 41 families were identified as being utilized by orangutans, with seven species scored as 2 i.e. of high importance to orangutans in KNP. These seven species were: *Dracontomelon dao*, *Merremia mammosa*, *Kleinhovia hospita*, *Alangium hirsutum*, *Dillenia reticulata*, *Callicarpa pentandra* and *Ficus obpyramidata*. The most utilized families in this database of orangutan food plants were *Moraceae*, *Anacardiaceae*, *Annonaceae* and *Phyllanthaceae* (Table 3).

Given that the list used to rank species is only a sub-selection of plants available in KNP, and that not all of these are available for restoration, we investigated which are preferred plant families. In cases where preferred species are not available for reforestation, this provides a useful index of family level preference, i.e. families from which to choose species from the list in Appendix 1 should a preferred species not be commercially available or in stock.

In order to identify preferred families, the number of species recorded as utilized by orangutans was divided by the number of species known to occur for each family in KNP. Results were then scaled to create a preference score, where positive scores indicate preferred families, while negative scores indicate families used less than expected given the number of species represented in the family. Using this index Moraceae and Anacardiaceae were preferred families, while Annonaceae and Phyllanthaceae were utilized less frequently than expected given the number of species recorded in the park. For families with more than two species, other families that were important were Loganiacae and Malvaceae. Conversely, families that were under-utilized given the number of species were: Rubiaceae, Dipterocarpaceae, Lauraceae, Euphorbiaceae and Fabaceae.

The female orangutan 'Ann', taken by hunters from the wild as an infant, suffers psychological problems that complicate reintroduction. She now lives at Samboja Lestari.

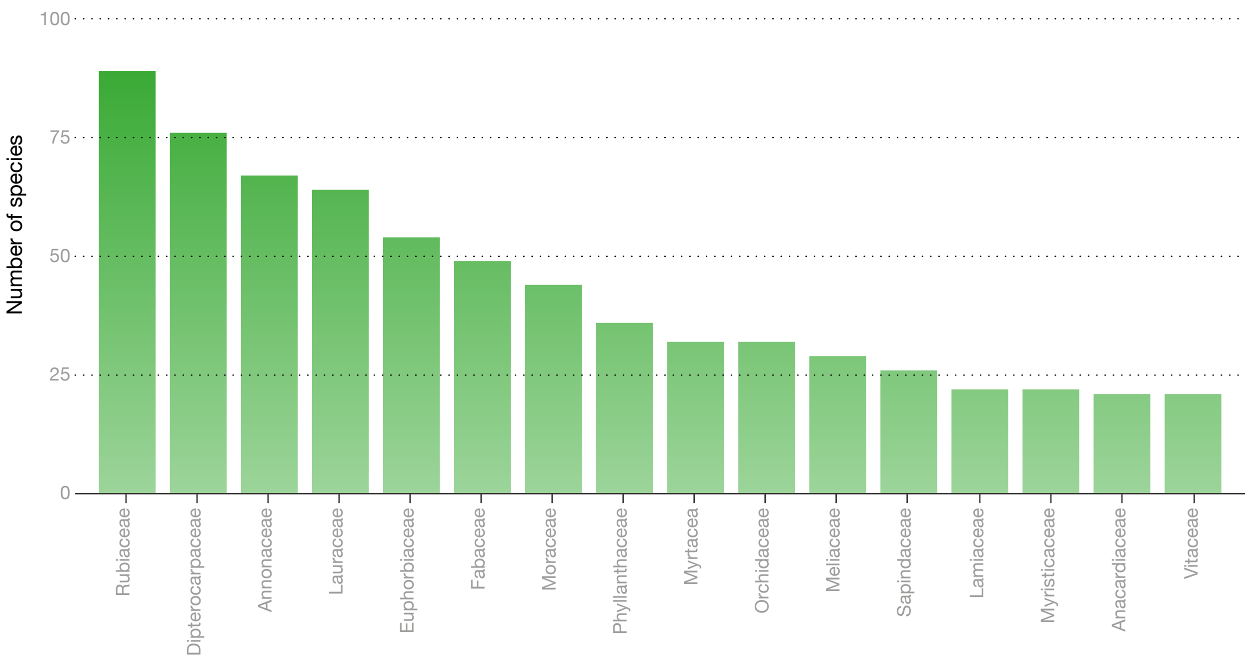


Figure 11. The most species rich tree and plant families of KNP: families with more than 20 species are illustrated.

Table 3. Plant families from KNP utilized by orangutans, with the number of species found within the park; the number of species which have been recorded as used by orangutans (from Russon et al. (2009)); the percentage of those used; and a preference weighting (from -2.47 indicating no species in the family are used, to 2.47 where all species in the family are used).

Family	Total spp in KNP	Species used by orangutans	Percentage used	Preference
Moraceae	44	26	59%	1.08
Anacardiaceae	21	9	43%	0.53
Annonaceae	67	9	13%	-0.47
Phyllanthaceae	36	8	22%	-0.18
Euphorbiaceae	54	7	13%	-0.49
Fabaceae	49	7	14%	-0.45
Malvaceae	13	7	54%	0.90
Burseraceae	17	4	24%	-0.13
Loganiaceae	4	4	100%	2.47
Apocynaceae	12	3	25%	-0.08
Dilleniaceae	8	3	38%	0.34
Dipterocarpaceae	76	3	4%	-0.80
Meliaceae	29	3	10%	-0.58
Sapindaceae	26	3	12%	-0.54
Combretaceae	6	2	33%	0.20
Ebenaceae	14	2	14%	-0.45
Lamiaceae	22	2	9%	-0.62
Melastomataceae	17	2	12%	-0.53
Rubiaceae	89	2	2%	-0.86
Arecaceae	17	1	6%	-0.73
Aspleniaceae	2	1	50%	0.77
Chrysobalanaceae	6	1	17%	-0.36
Clusiaceae	8	1	13%	-0.51
Convolvulaceae	4	1	25%	-0.08
Gnetaceae	1	1	100%	2.47
Irvingiaceae	1	1	100%	2.47
Lauraceae	64	1	2%	-0.88
Marantaceae	5	1	20%	-0.25
Myristicaceae	22	1	5%	-0.78
Myrtaceae	32	1	3%	-0.83
Piperaceae	6	1	17%	-0.36
Putranjivaceae	4	1	25%	-0.08
Rutaceae	20	1	5%	-0.76
Tetramelaceae	1	1	100%	2.47
Urticaceae	6	1	17%	-0.36
Vitaceae	21	1	5%	-0.77
Zingiberaceae	19	1	5%	-0.75

In which tree species do orangutans prefer to make their nests?

Orangutans normally make new nests for sleeping every night. These are often close to food trees or, occasionally, in them. We examined OKP databases that represent KNP's north-eastern Mentoko sector, one of 861 nests recorded during nest censuses for the period 2015-2017 and the other of 252 nests recorded during behavioural observations of individual orangutans for the period 2010-2014, representing a combined nest dataset of 1,066 nests. Many of the trees in which nests were made were not identified to species level (identification to species level: 61%), but many were identifiable at the genus level: (78.9%) and accordingly to family level: (88.9%). Nests were found mostly in large trees (19.2 ± 6.8m) represented by 28 families, with the top 10 families and genera of trees in which nests were located illustrated in Figure 12. *Eusideroxylon zwageri* (Lauraceae) was the most frequently used species for nesting purposes (218 nests), followed by unidentified Dipterocarps (101 nests), *Macaranga gigantea* (Euphorbiaceae, 87 nests) and *Dracontomelon dao* (Anacardiaceae, 81 nests).

The time period that these nest censuses sampled primarily represented El Niño drought conditions (2015-16; NOAA SST criteria, all of 2015 and through Q2 in 2016) followed by ENSO-neutral to La Niña high rainfall conditions (Q3-4 2016 and all of 2017). A Dipterocarp masting event during the observation period may explain the large number of nests in this family for this sampling period. Also note that all of these data represent only a very small part of KNP and the park's habitat (and therefore its vegetation and available nesting trees), so nest selection may differ considerably in other locations. For this reason, general interpretations need to be cautious.

Mother and infant orangutan at Prevab

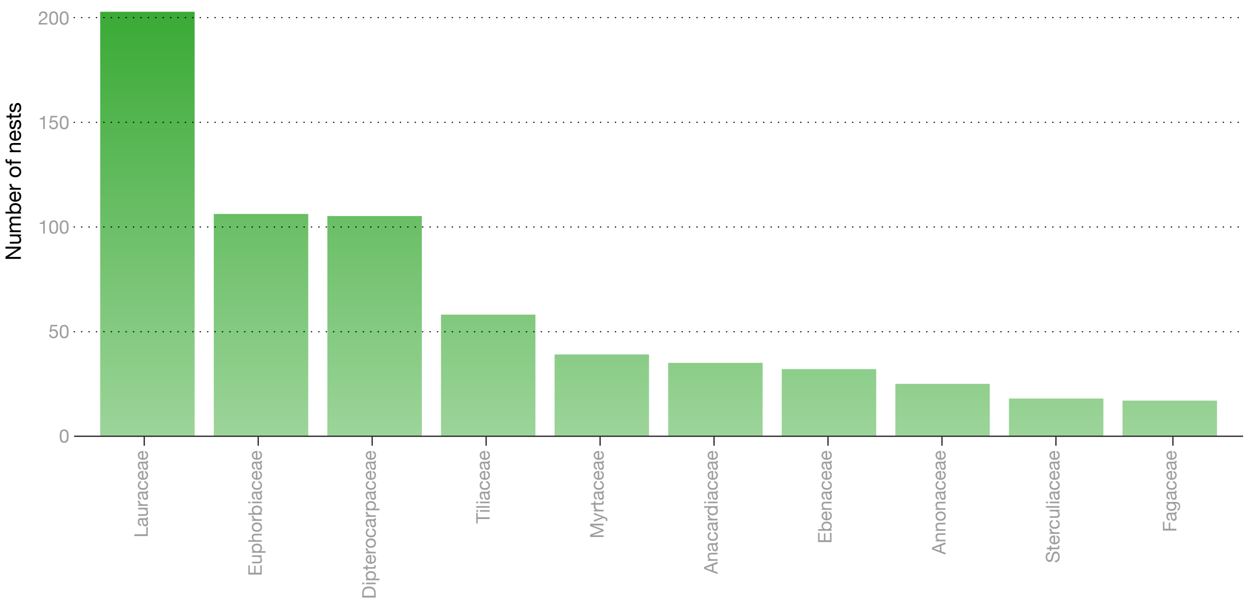


Figure 12. The top 10 tree families (top) and genera (bottom) used by orangutan for nesting in KNP during the 2010-2017 period.

Which tree and plant species are of greatest importance for ecological, economic and social reasons?

At the workshop, experts rated the plant species in Appendix 1 based on five criteria using a binary system (0 = no, 1 = yes, 0.5 = unknown) for each species:

1. Iconic (large, emergent trees or interesting trees e.g. strangler figs that would be of interest to tourists)
2. Old growth (climax species dominating 'primary' forest)
3. Commercially important (species harvested for timber or local use)
4. Locally threatened
5. Ecologically important (e.g. important food sources for birds and mammals)

The 'ecologically important' category included a score of -1 for invasive or pest species. A sum of the scores gave a **regional importance score** with range -1 to 5, representing the overall importance of each species across these dimensions (i.e., old growth, iconicity, ecological, commercial, and threatened).

Dipterocarps dominated the top ranked species across all categories, with all ten species considered in this assessment in the list of 13 most important species (Table 4). A further 11 species were identified as being locally threatened: *Durio dulcis*, *Durio oxleyanus*, *Intsia palembanica*, *Sindora coriacea*, *Magnolia tsiampacca*, *Borassodendron borneense*, *Dillenia excelsa*, *Eusideroxylon zwageri*, *Dendrobium anosmum*, *Palaquium stenophyllum*, *Korthalsia* spp. and *Daemonorops* spp. The last two species are rattans, with the stems of the Daemonorops harvested for their multi-purpose cores, used for making canes, furniture etc. Other locally threatened species are harvested for food or timber. By contrast, species of low importance were represented by a wide variety of families. These were mostly pioneer or alien invasive species.

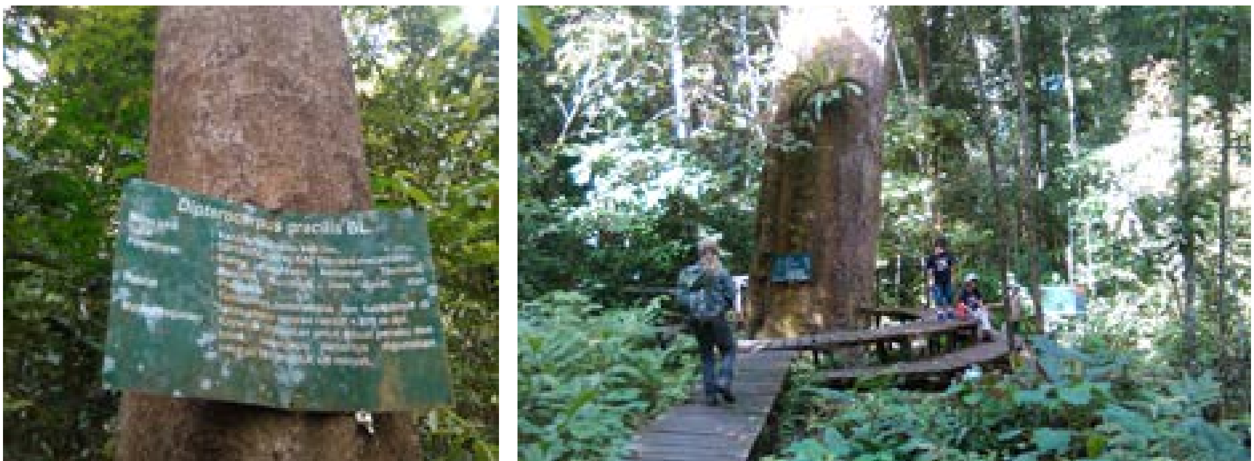
Area endemic species should be used as a priority whenever reforestation is considered. These species are likely to be at greater risk of extinction due to their rarity and the threats facing the park, making them a higher priority for conservation projects. Since this assessment generally did not consider rare species due to the selection criteria, the following table (Table 5) should not be considered complete, and further use of local inventories should be used wherever possible.

Table 4. Importance scores for the top and bottom ranked species based on iconic status, old growth, ecological and commercial importance. Top ranked species scored 5 out of a possible 5 for this score, with bottom ranked species scoring -1, representing mostly invasive species.

Top ranked species		Bottom ranked species	
Name	**Family**	**Name**	**Family**
Dipterocarpus verrucosus	Dipterocarpaceae	*Piper aduncum*	Piperaceae
Shorea ferruginea	Dipterocarpaceae	*Lantana camara*	Verbenaceae
Shorea inappendiculata	Dipterocarpaceae	*Melastoma malabathricum*	Melastomataceae
Shorea johorensis	Dipterocarpaceae	*Clidemia hirta*	Melastomataceae
Shorea leprosula	Dipterocarpaceae	*Eupatorium inulaefolium*	Asteraceae
Shorea pauciflora	Dipterocarpaceae	*Acacia mangium*	Fabaceae
Shorea polyandra	Dipterocarpaceae	*Imperata cylindrica*	Poaceae
Sindora coriacea	Fabaceae	*Urena lobata*	Malvaceae
Magnolia tsiampacca	Magnoliaceae	*Wedelia biflora*	Asteraceae
Eusideroxylon zwageri	Lauraceae	*Passiflora foetida*	Passifloraceae
Shorea ovalis	Dipterocarpaceae	*Ageratum conyzoides*	Asteraceae
Hopea mengerawan	Dipterocarpaceae	*Spathodea campanulata*	Bignoniaceae
Hopea rudiformis	Dipterocarpaceae	*Solanum sp.*	Solanaceae
		Mikania scandens	Asteraceae

Table 5. Species identified as being mostly restricted to Borneo, together with their regional importance score.

Name	Family	Importance Score
Monocarpia euneura	Annonaceae	1
Polyalthia borneensis	Annonaceae	1
Mezzettia umbellata	Annonaceae	2
Monoon borneense	Annonaceae	2
Borassodendron borneense	Arecaceae	4
Dillenia borneensis	Dilleniaceae	2
Shorea ferruginea	Dipterocarpaceae	5
Shorea polyandra	Dipterocarpaceae	5
Hopea rudiformis	Dipterocarpaceae	5
Macaranga pearsonii	Euphorbiaceae	1
Spatholobus oblongifolius	Fabaceae	0
Phytocrene racemosa	Icacinaceae	0
Alseodaphne elmeri	Lauraceae	1
Strychnos polytrichantha	Loganiaceae	0
Durio lanceolatus	Malvaceae	2
Durio kutejensis	Malvaceae	3
Pentace laxiflora	Malvaceae	3
Durio dulcis	Malvaceae	4
Stachyphrynium borneensis	Marantaceae	0
Artocarpus odoratissimus	Moraceae	1
Artocarpus tamaran	Moraceae	1
Ficus cereicarpa	Moraceae	2
Syzygium tawahense	Myrtaceae	2
Melicope lunu-ankenda	Rutaceae	1



Dipterocarps are regionally important trees, vulnerable to climate change and over harvesting. Their iconic status means they can serve as important tourism attractions.

A trait-based climate change vulnerability analysis: methods and rationale

We used a trait-based approach to assess climate change vulnerability of KNP's focal tree species following Foden et al. (2013). The framework guides users to independently measure three dimensions of climate change vulnerability, namely **sensitivity** (the lack of potential for a species to persist *in situ*), **exposure** (the extent to which each species' physical environment will change) and **low adaptive capacity** (a species' inability to avoid the negative impacts of climate change through dispersal and/or microevolutionary change). These are typically quantified, often using expert judgment (Foden and Young 2016, Pacifici et al. 2015), and then combined with measures of exposure to projected change to generate and overall climate change vulnerability ranking or score (e.g. Carr et al. 2013, 2014, Foden et al. 2013, Young et al. 2015, Böhm et al. 2016). The three dimensions can then be used to allocate species to one of four classes of climate change vulnerability, each with different implications for conservation (Figure 13). Species are considered to be highly climate change vulnerable if they qualify as highly sensitive, highly exposed and of lowest adaptive capacity.

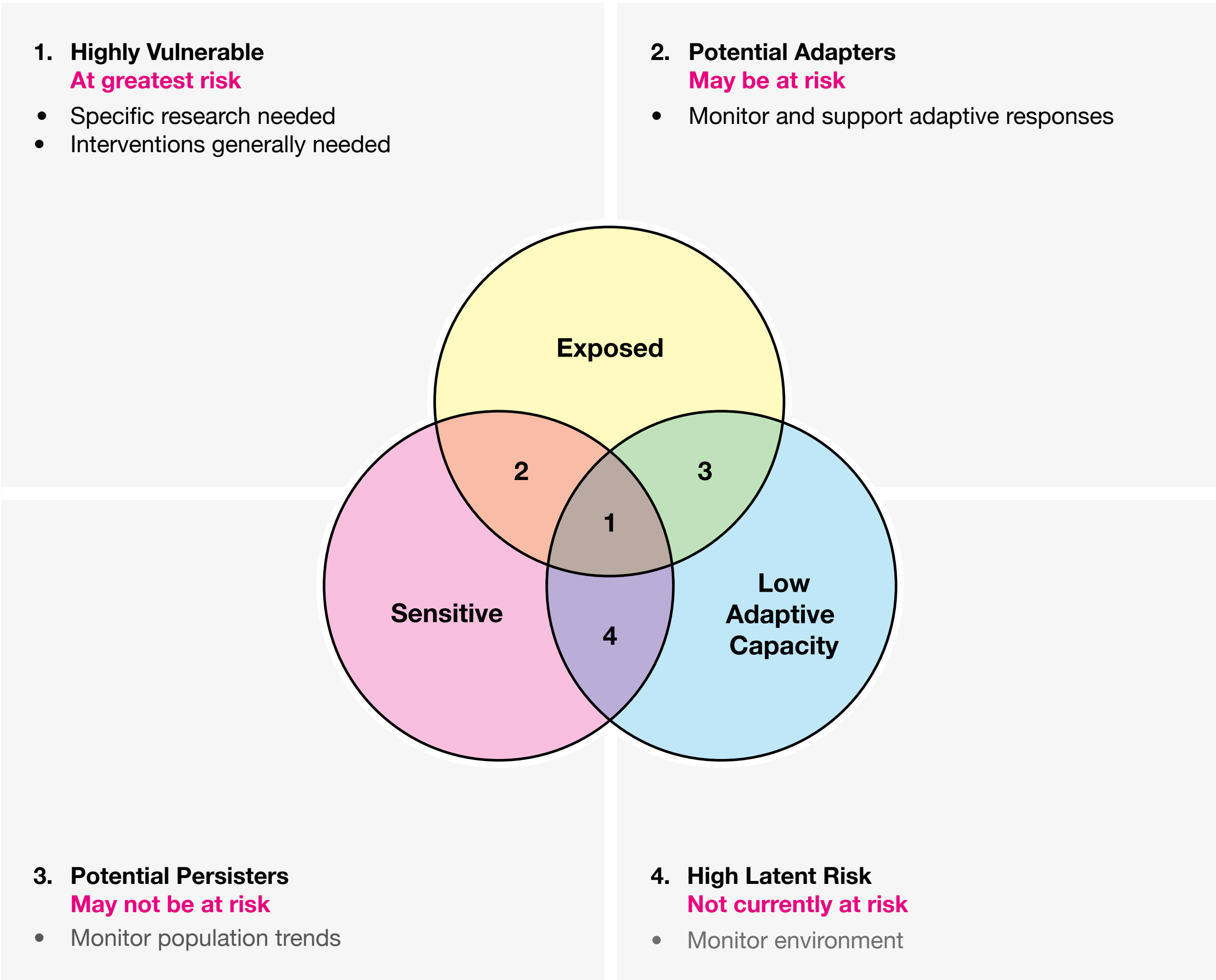


Figure 13. Framework to assess the impacts of climate change on species (adapted from Foden et al. (2013), doi:10.1371/journal.pone.0065427.g001). Combinations of the three dimensions of climate change vulnerability, namely sensitivity, exposure and low adaptive capacity describe four distinct classes of climate change vulnerable species, each with particular implications for conservation prioritisation and strategic planning. Species that are 'highly climate change vulnerable' (1), being sensitive, exposed and of low adaptive capacity, are of greatest concern. They are the first priority for monitoring responses to climate change and for assessment of the interventions needed to support them. 'Potential adapters' (2) are sensitive and exposed but high adaptive capacity species that may be able to mitigate negative climate change impacts by dispersal or microevolution, although close monitoring is needed to verify this. 'Potential persisters' (3) have low adaptive capacity and are exposed (but are not sensitive) so may be able to withstand climate change in situ by themselves, but again, monitoring is needed to ensure that the assumptions about insensitivity are realized in practice. Finally, species of 'high latent risk' (4) have low adaptive capacity and are sensitive (but are not exposed). Although not of immediate concern if climate change projections and emissions scenarios are accurate, they could become climate change vulnerable if exposed beyond selected time frames (e.g. 2050).

To apply the climate change vulnerability assessment method to plants (Table 6), input was gathered from plant experts from IUCN's Species Survival Commission, including from plant Specialist Group Chairs and Stand-alone Red List Authority coordinators, who coordinated feedback from their wider membership. These experts identified 63 potential criteria for assessing climate change vulnerability through sensitivity and adaptation traits. After the 2017 Kutai workshop the most useful 31 sensitivity traits (where answers were not dominated by a lack of information or unanimous in response; see 'uncertainties and knowledge gaps' section) were selected for further analysis (Appendix 2). Of the 31 sensitivity traits, 28 focused on vulnerability to climate change, and 3 on resilience to climate change. Twelve adaptability traits were considered, seven of which were associated with vulnerability and five with resilience (Appendix 2). The workshop group then answered each question for all of the 247 target species, reaching conclusions through consensus. Although other applications of this process have been undertaken (Böhm et al. 2016, Carr et al. 2013, Young et al. 2015) this work in KNP marks their first ever application in the context of forest restoration.

Using the data collected at the workshop, we created a climate change vulnerability score to rank KNP plant species according to their relative vulnerability to climate change. Of the traits for which data were collected, we made use of those that were non-uniform in response (species were included in both yes and no categories of answers), or that were not obviously correlated with other traits analysed. This included 16 of the 31 sensitivity traits and 9 of the 12 adaptability traits, as well as a range score (Appendix 3). Rankings were given to each answer, as follows: 0 for 'no' and 'unknown', and 1 for 'yes'; or -1 where the trait is likely to confer resilience or benefit under climate change (termed 'resilience'). The use of 'unknown' scores for quantifying uncertainty is described below.

The resulting overall climate change vulnerability scores for each species are shown in Appendix 1. Scores were obtained additively across the set traits and ranged from -2 to 3 for sensitivity traits, while adaptability ranged from -4 to 2. Climate change vulnerability analysis scores (ccva) represent the sum of the scores for sensitivity, adaptability and range, with negative values indicating climate resilience, and high positive values representing high vulnerability to climate change. A maximum vulnerability score of 19 is theoretically possible based on the sum of all vulnerability scores with no resilience traits, but was not attained for any species: the maximum was 6. In the next section we present summary patterns observed using the above strategy, which is an optimistic scenario for vulnerability to climate change given uncertainty. We deal with uncertainty later to illustrate the effects of changing the weighting given to the 'unknown' group. The uncertainty score can be interpreted as a measure of error of the ccva score.

Environmental monitoring, Mawas

Table 6. Trait sets associated with species' heightened sensitivity and low adaptive capacity to climate change, modified from Foden et al 2013

Sensitivity

1. Specialised habitat and/or microhabitat requirements

As climate change-driven environmental changes unfold, species that are less tightly coupled to specific conditions and requirements are likely to be more resilient because they will have a wider range of habitat and microhabitat options available to them. Sensitivity is further increased for species with several life stages, each requiring different habitats or microhabitats (e.g. water-dependent larval amphibians). We note, however, that this does not hold in all cases, and extreme specialization may allow some species to escape the full impacts of climate change exposure (e.g. deep sea fishes).

2. Environmental tolerances or thresholds (at any life stage) that are likely to be exceeded due to climate change

Species with physiological tolerances that are tightly coupled to specific environmental conditions (e.g. temperature or precipitation regimes, water pH or oxygen levels) are likely to be particularly sensitive to climatic changes (e.g. tropical ectotherms). However, even species with broad environmental tolerances may already be close to thresholds beyond which physiological function quickly breaks down (e.g. drought tolerant desert plants).

3. Dependence on environmental triggers that are likely to be disrupted by climate change

Many species rely on environmental triggers or cues to initiate life stages (e.g. migration, breeding, egg laying, seed germination, hibernation and spring emergence). While cues such as day length and lunar cycles will be unaffected by climate change, those driven by climate and season may alter in both their timing and magnitude, leading to asynchrony and uncoupling with environmental factors (e.g. mismatches between advancing spring food availability peaks and hatching dates). Climate change sensitivity is likely to be compounded when different sexes or life stages rely on different cues.

4. Dependence on interspecific Interactions that are likely to be disrupted by climate change

Climate change driven alterations in species' ranges, phenologies and relative abundances may affect their beneficial inter-specific interactions (e.g. with prey, pollinators, hosts and symbionts) and/or those that may cause declines (e.g. with predators, competitors, pathogens and parasites). Species are likely to be particularly sensitive to climate change if, for example, they are highly dependent on one or few specific resource species and are unlikely to be able to substitute these for other species.

5. Rarity

The inherent vulnerability of small populations to Allee effects and catastrophic events, as well as their generally reduced capacity to recover quickly following local extinction events, suggest that many rare species will be more sensitive to climate change than common species. Rare species include those with very small population sizes, as well as those that may be locally abundant but are geographically highly restricted.

Low adaptive capacity

6. Poor dispersal ability

Intrinsic dispersal limitations: Species with low dispersal rates or low potential for long distance dispersal (e.g. land snails, ant and raindrop splash-dispersed plants) have lowest adaptive capacity since they are unlikely to be able to keep up with a shifting climate envelope.

Extrinsic dispersal limitations: Even where species are intrinsically capable of long distance or rapid dispersal, movement and/or successful colonisation may be reduced by low permeability or physical barriers along dispersal routes. These include natural barriers (e.g. oceans or rivers for terrestrial species), anthropogenic barriers (e.g. dams for freshwater species) and unsuitable habitats or conditions (e.g. ocean currents and temperature gradients for marine species). Species for which no suitable habitat or 'climate space' is likely to remain (e.g. Arctic ice-dependent species) may also be considered in this trait set.

7. Poor evolvability

Species' potential for rapid genetic change will determine whether evolutionary adaptation can result at a rate sufficient to keep up with climate change driven changes to their environments. Species with low genetic diversity, often indicated by recent bottlenecks in population numbers, generally exhibit lower ranges of both phenotypic and genotypic variation. As a result, such species tend to have fewer novel characteristics that could facilitate adaptation to the new climatic conditions.

Since direct measures of species' genetic diversity are few, proxy measures of evolvability such as those relating to reproductive rates and outputs, and hence the rate at which advantageous novel genotypes could accumulate in populations and species, may be useful. Evidence suggests that evolutionary adaptation is possible in relatively short timeframes (e.g. 5 to 30 years) but for most species with long generation lengths (e.g. large animals and many perennial plants) genetic or phenotypic selection will be too slow to have any serious minimising effect on climate change impacts.

Which species are most vulnerable to climate change?

The most climate change vulnerable families as determined by the mean ccva scores were Dipterocarpaceae (which included 7 of the 13 species with ccva score >2), Aspleniaceae and Vitaceae, with the most vulnerable species (ccva>2) listed in Table 7. Thus, Dipterocarpaceae were classified both as most important and most vulnerable to climate change according to this exercise (Figure 14). The family possessed a range of traits that could make them vulnerable to climate change: masting seed production, with seed production triggered by climate events, low seed dispersal distances, long life spans and age to first reproduction, and associations with mycorrhiza amongst others.

Species that are sensitive to climate change might survive if they are adaptable. Species that are of greatest concern in terms of climate change vulnerability are thus those species that are sensitive, but do not possess traits suggesting they will be able to adapt rapidly to changes. We identified 30 species that possess at least one sensitivity trait, and with unadaptability scores > 1 (i.e. species with low adaptability; Table 8).

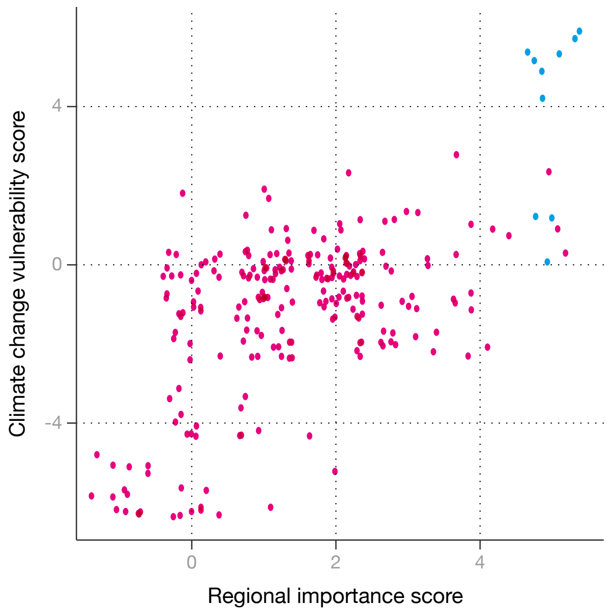


Figure 14. Dipterocarpaceae (blue) are both important and vulnerable to climate change, as seen here in relation to scores of other species (red).

Table 7. A list of species most vulnerable to climate change according to cumulative trait-based scores (ccva scores >2). CCVA = climate change vulnerability assessment score.

Name	Family	CCVA
Shorea ferruginea	Dipterocarpaceae	6
Shorea polyandra	Dipterocarpaceae	6
Shorea inappendiculata	Dipterocarpaceae	5
Shorea johorensis	Dipterocarpaceae	5
Shorea leprosula	Dipterocarpaceae	5
Shorea pauciflora	Dipterocarpaceae	5
Dipterocarpus verrucosus	Dipterocarpaceae	4
Borassodendron borneense	Arecaceae	3
Alangium hirsutum	Cornaceae	2
Asplenium nidus	Aspleniaceae	2
Eusideroxylon zwageri	Lauraceae	2
Tetrastigma rafflesiae	Vitaceae	2
Tetrastigma pedunculare	Vitaceae	2

Reforestation efforts in the Mawas supported by volunteers. Follow up and monitoring of planting is required - in this case the sapling is being attacked by caterpillars and the nearby ferns pose a fire hazard.

Which traits contributed to climate change vulnerability?

Ten species are masting species, of which seven require a period of wet and then drought for seed set. These are all Dipterocarps: *Dipterocarpus verrucosus*, S*horea ferruginea*, *Shorea inappendiculata*, *Shorea johorensis*, *Shorea leprosula*, *Shorea pauciflora*, *Shorea polyandra*. Three species require drought followed by rain for seeding: *Shorea ovalis*, *Hopea mengerawan*, *Hopea rudiformis*. The Dipterocarps are also species where seed production is triggered by temperature and are known to have specialised relationships with mycorrhiza.

Species with associations with mycorrhizal associations, such as the Dipterocarps, may be especially vulnerable to climate change, although general impacts of climate change on below-ground process responses to elevated CO_2 and temperature are still poorly quantified (Pendall et al. 2004). Smits (1994) demonstrated the negative impact of high topsoil temperatures and lack of oxygen upon functioning and survival of dipterocarp ectomycorrhizae. Fire has a negative impact on mychorrhizal communities. Severe reduction in ectomycorrhizal bodies in burnt forests has been attributed to changed microclimate, changes in the input of leaf litter, volatilization of organically bound nutrients, the death of host trees, and sterilization of upper layers of the soil by the fires (Certini 2005).

Pentaspadon motleyi was identified as a freshwater habitat specialist. It occurs in swamps, along rivers, and areas subject to flooding. It is typically found in undisturbed forest at altitudes up to 200 m and although it is described as having edible fruits (https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=3059) this is a not yet a recorded food for orangutans in KNP. Only Donax canniformis, a widespread understorey herb, was identified as requiring a specific flooding regime: https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=5607.

The following five species were identified as habitat specialists: *Dracontomelon dao*, *Gluta renghas*, P*entaspadon motleyi*, *Terminalia catappa*, *Pterospermum javanicum*. All of these species are associated with stream or riverine habitats. Careful consideration of their habitat requirements is needed if these species are to be included in reforestation efforts.

Eight species (mostly trees with soft wood) were judged to be vulnerable to increasing storm frequency/intensity: *Irvingia malayana*, *Vernonia arborea*, *Neolamarckia cadamba*, *Nauclea subdita*, *Melicope glabra*, *Melicope lunu-ankenda*, *Pometia pinnata*, *Homalanthus populneus*.

Two species grow exclusively on flat terrain: *Magnolia tsiampacca* and *Donax canniformis*, while two species grow exclusively in poorly drained areas: *Mallotus muticus* and *Pterospermum javanicum*. Twenty-eight species were identified as having adventitious roots, but in combination with the previous two traits, no species were identified as sensitive to water logging (being inundation vulnerable species).

Forty species require specialist pollinators or groups of pollinators, but these were generically specialist e.g. bird or beetle. One species has specialised seed dispersal: *Borassodendron borneense* - extinct megafauna like rhinoceros; but is also dispersed by humans and orangutans. Given this palm's vulnerability to climate change, but utility in terms of fire recovery, this should be a priority species for restoration efforts around Kutai.

Species with reproductive ages greater than 10 years are indicated in Table 9. Many of these species are ecologically and economically important and should be included in restoration schemes wherever possible. However, these species will be especially vulnerable to short term disturbance: so they should be included in later stages of reforestation activities; or planted using individuals that have already reached reproductive age through cultivation in nursery environments, if these are still of a manageable size.

Two species were identified as having low fecundity (1-10 seeds per year): *Goniothalamus macrophyllus* and *Goniothalamus ridleyi*. These, and species with similar ecological traits, are generally vulnerable and should be included in conservation focused reforestation efforts.

Table 8. Species that are both sensitive to climate change and low in adaptive capacity (unadaptable).

Name	Family	Unadaptability	Sensitivity	Orangutan food score
Dipterocarpus verrucosus	Dipterocarpaceae	1	3	0
Shorea ferruginea	Dipterocarpaceae	2	3	0
Shorea inappendiculata	Dipterocarpaceae	2	3	0
Shorea johorensis	Dipterocarpaceae	2	3	0
Shorea leprosula	Dipterocarpaceae	2	3	1.5
Shorea pauciflora	Dipterocarpaceae	2	3	0
Shorea polyandra	Dipterocarpaceae	2	3	1.5
Borassodendron borneense	Arecaceae	1	1	0

Table 9. Species with age of reproduction >10 years. Most of these species are also regionally important (Importance score).

Name	Family	Importance score
Dipterocarpus verrucosus	Dipterocarpaceae	5
Shorea ferruginea	Dipterocarpaceae	5
Shorea inappendiculata	Dipterocarpaceae	5
Shorea johorensis	Dipterocarpaceae	5
Shorea leprosula	Dipterocarpaceae	5
Shorea pauciflora	Dipterocarpaceae	5
Shorea polyandra	Dipterocarpaceae	5
Shorea ovalis	Dipterocarpaceae	5
Hopea mengerawan	Dipterocarpaceae	5
Hopea rudiformis	Dipterocarpaceae	5
Intsia palembanica	Fabaceae	4
Sindora coriacea	Fabaceae	5
Eusideroxylon zwageri	Lauraceae	5
Boschia griffithii	Malvaceae	2
Durio lanceolatus	Malvaceae	2
Durio kutejensis	Malvaceae	3
Durio dulcis	Malvaceae	4
Durio oxleyanus	Malvaceae	4
Palaquium stenophyllum	Sapotaceae	3

How vulnerable are species of importance?

Orangutan food plants spanned the range of climate change vulnerability scores, meaning that orangutans have not been recorded feeding primarily on species that are vulnerable to climate change (linear model of climate change vulnerability as a function of orangutan use: yes = 0.29 ± 0.28, t = 1.04, p = 0.30, Figure 15). However, orangutan food plants tend to be more associated with plants ranking highly on the regional importance score (linear model of importance as a function of orangutan use: yes = 0.41 ± 0.18, t = 2.25, p = 0.03), but likely as this score included species that are ecologically important (i.e. food species for birds and animals).

With few exceptions, we found that plant species classed as having achieved pest status in some part of the world were generally more climate change resilient (negative scores on our ccva index; Figure 16). It is also interesting to note that species ranked as being commercially important ranked higher on average in terms of vulnerability to climate change than others (non-commercial average: 4.6 ± 3.8, commercial average: 6.6 ± 3.3, t = 3.4, p < 0.01; Figure 16).

Which species are most resilient to climate change?

Many of the species considered had traits that conferred an element of resilience to aspects of climate change: 126 species are desiccation tolerant; and 171 species had seed dispersal distances > 1km. However, the species with the greatest resilience to climate change were dominated by the set of potentially invasive species (pest species): 42 were identified, with many (40) established outside their known native range (Table 10).

In terms of early stage succession species that were not classified as pest species, the following were identified (Table 11). It should be noted that early succession species should not dominate any restoration effort or be used for enrichment planting, due to lower long-term survival rates (Charles et al. 2018).

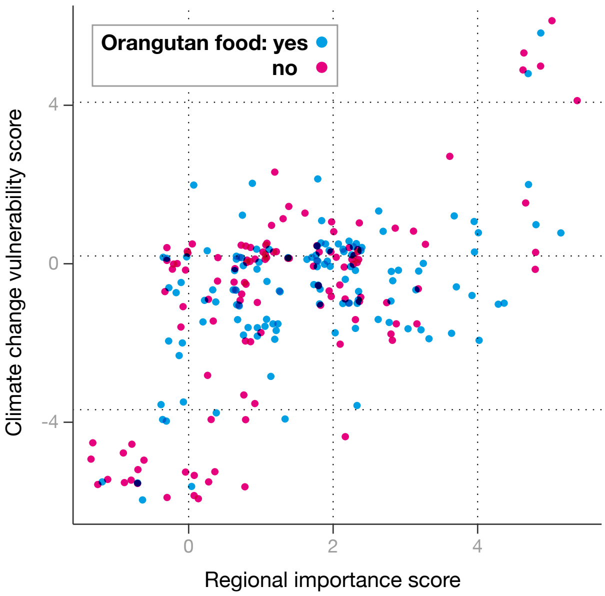
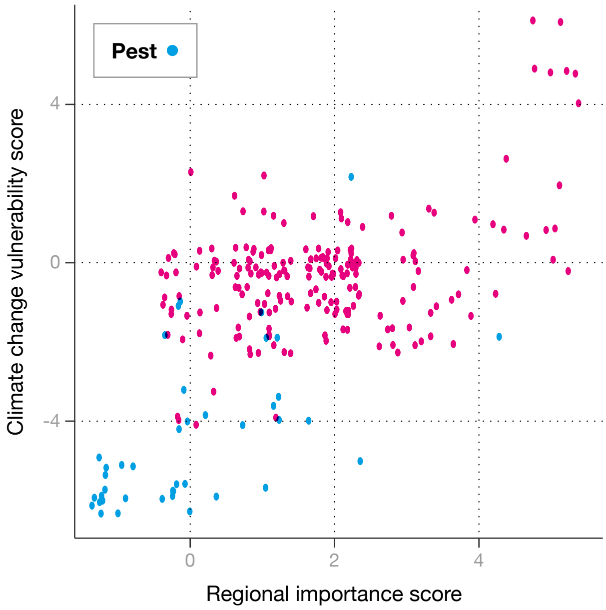


Figure 15. In the ordination of climate change vulnerability against importance, species used by orangutans (blue) span the range from pest species (lower left, importance score < 0) to Dipterocarps (top right with importance score > 4).



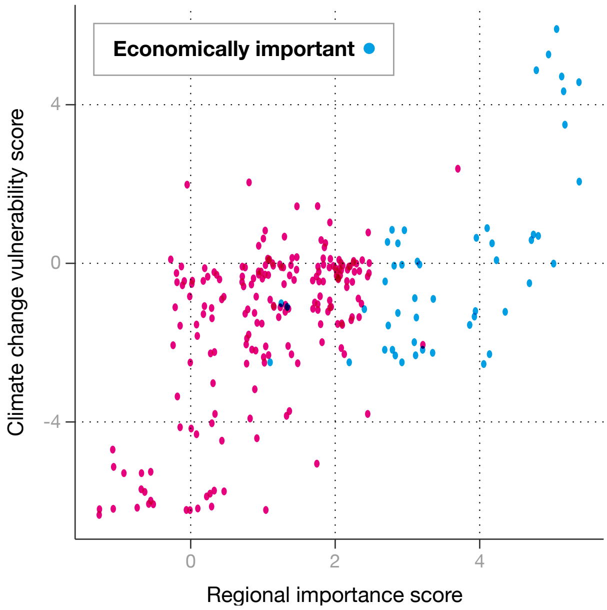


Figure 16. In the ordination of climate change vulnerability against importance, pest species were mostly neither vulnerable to climate change nor ranked with high regional importance (top chart). This contrasts with economically important species (bottom chart), many of which were more likely to be ranked as vulnerable to climate change.

Table 10. Species 'resilient' to climate change (i.e. ccva scores < 1). Species in blue are preferred species for KNP forest rehabilitation to support orangutans. Yellow species can be considered given that they are utilized by orangutans. Species in red are species identified as potentially invasive and so should not be used in restoration schemes due to their potential to cause management problems in the future.

Name	Family	Pest	Orangutan food
Kleinhovia hospita	Malvaceae		Yes
Cratoxylum sumatranum	Hypericaceae		No
Colona serratifolia	Malvaceae		No
Mischocarpus pentapetalus	Sapindaceae		Yes
Croton argyratus	Euphorbiaceae	Yes	Yes
Endospermum peltatum	Euphorbiaceae	Yes	Yes
Macaranga gigantea	Euphorbiaceae	Yes	Yes
Macaranga tanarius	Euphorbiaceae	Yes	Yes
Omphalea bracteata	Euphorbiaceae	Yes	Yes
Piper aduncum	Piperaceae	Yes	Yes
Melastoma malabathricum	Melastomataceae	Yes	Yes
Clidemia hirta	Melastomataceae	Yes	Yes
Spatholobus spp.	Fabaceae	Yes	Yes
Mallotus macrostachyus	Euphorbiaceae	Yes	No
Mallotus paniculatus	Euphorbiaceae	Yes	No
Lantana camara	Verbenaceae	Yes	No
Eupatorium inulaefolium	Asteraceae	Yes	No
Acacia mangium	Fabaceae	Yes	No
Imperata cylindrica	Poaceae	Yes	No
Merremia peltata	Convolvulaceae	Yes	No
Dioscorea spp.	Dioscoreaceae	Yes	No
Urena lobata	Malvaceae	Yes	No
Alpinia ligulata	Zingiberaceae	Yes	No
Wedelia biflora	Asteraceae	Yes	No
Trema tomentosa	Cannabaceae	Yes	No
Passiflora foetida	Passifloraceae	Yes	No
Ageratum conyzoides	Asteraceae	Yes	No
Homalanthus populneus	Euphorbiaceae	Yes	No
Spathodea campanulata	Bignoniaceae	Yes	No
Solanum spp.	Solanaceae	Yes	No
Nephrolepis spp.	Lomariopsidaceae	Yes	No
Lygodium circinatum	Schizaeacaceae	Yes	No
Mikania scandens	Asteraceae	Yes	No

Table 11. Pioneer or early stage succession species. Species utilized by orangutans are in blue, with those most climate resilient also in bold. All these species would be acceptable as part of a set of species selected for reclamation and rehabilitation projects, but not for enrichment planting as they likely do not compete well with primary forest species and have shorter lifespans.

Name	Family	Orangutan food
Kleinhovia	Malvaceae	Yes
Alstonia scholaris	Apocynaceae	Yes
Fordia splendidissima	Fabaceae	Yes
Neolamarckia cadamba	Rubiaceae	Yes
Nauclea subdita	Rubiaceae	Yes
Vitex pinnata	Lamiaceae	Yes
Willughbeia angustifolia	Apocynaceae	Yes
Terminalia foetidissima	Combretaceae	Yes
Terminalia catappa	Combretaceae	Yes
Melicope glabra	Rutaceae	Yes
Callicarpa pentandra	Lamiaceae	Yes
Dillenia reticulata	Dilleniaceae	Yes
Cratoxylum sumatranum	Hypericaceae	No
Colona serratifolia	Malvaceae	No
Glochidion zeylanicum var. arborescens	Phyllanthaceae	No
Alstonia macrophylla	Apocynaceae	No
Willughbeia coriacea	Apocynaceae	No
Pentace laxiflora	Malvaceae	No
Uncaria gambir	Rubiaceae	No
Vernonia arborea	Asteraceae	No
Melicope lunu-ankenda	Rutaceae	No

A local community nursery provide income opportunities and indigenous trees.

Uncertainties and knowledge gaps

Several traits did not provide useful information on vulnerability for KNP tree species (answers were uniform being only 'no' or 'yes' for all species assessment). For instance, no species required **trampling** of habitat in order to enable its growth, there were **no confirmed host-specific parasites or epiphytes**, all species can reproduce sexually, and all species can produce **1 or more seeds per year** on average.

No species were identified as vulnerable for the following traits, but answers may have been 'unknown' for some or many species:

- Microhabitat dependent (U = 73)
- Vulnerable to decreased flooding (U = 61)
- Found exclusively in habitats that are vulnerable to saltwater intrusion (U = 2)
- Only found in landscapes sensitive to landslides (U = 2) Specific humidity requirements (e.g. occurs only in coastal fog belts, cloud forests etc.)
- Undergo marked population fluctuations as a response to recurring ocean-atmosphere oscillations (e.g. El Niño)
- Require a drop in water level in order to flower or germinate (U = 30)
- Require a change in temperature in order to germinate
- Known Predation, Competition, Parasitism, Disease or other negative interspecific interactions that are likely to become a threat for this species due to climate change
- Seed dispersal mechanism herpochorous or ballochorous
- Specialized seed dispersal agents (e.g. key animal, U = 4)
- No species had a known lack of genetic diversity (e.g. a known historic bottleneck), although this was suspected for Dipterocarpaceae due to harvest-related fragmentation

101 species were indicated to be inundation intolerant, but levels of uncertainty were high for this trait (Unknown (U) = 132), while 15 species are vulnerable to increased flooding (U = 80). However, given that the elevation gradient of KNP extends to >300m, these traits are not considered very important overall, although they may well be of concern locally for riverine species that are important to orangutans.

At least one trait of every species listed was scored as Unknown. To investigate the role of 'unknown' data in the assessment we created an uncertainty score, which we used to confer confidence that our scores represented the real vulnerability of the species to climate change. This was calculated as the sum of 'unknown' scores across a species, for example, if experts specified 'unknown' as an answer 10 times, the uncertainty score was 10. This index ranged from 1 to 10 for the focal species, with 1 highlighting species with highest confidence in vulnerability scores, and 10 indicating low confidence. There was a high level of uncertainty in assigning traits to species: 101 species had uncertainty scores > 4, being the median uncertainty score (Table 12). Magnoliaceae, Loganiaceae and Gnetaceae had the highest mean uncertainty scores of the 15 families with mean uncertainty scores > 4. These families should be the target of future focused studies that quantify traits associated with climate change vulnerability.

Table 12. Mean uncertainty scores across the set of species for each plant family for those families where uncertainty was greater than the median uncertainty score (4). The number of species for each family is indicated (n).

Family	Uncertainty	n
Magnoliaceae	10	1
Loganiaceae	7	4
Gnetaceae	6	1
Dilleniaceae	5.6	3
Anisophylleaceae	5	1
Annonaceae	5	34
Chrysobalanaceae	5	1
Clusiaceae	5	1
Ebenaceae	5	2
Orchidaceae	5	1
Putranjivaceae	5	1
Phyllanthaceae	4.9	12
Moraceae	4.7	42
Combretaceae	4.5	2
Anacardiaceae	4.1	16

Which tree species are fire-resilient?

Rainforests contain many species that are believed to be poorly adapted to fire, since this is generally a rare ecological phenomenon. However, two species are notable for their resilience to fire: the endemic palm species, *Borassodendron borneense*, and *Eusideroxylon zwageri*. These were described as 'strongly resistant to fire' (Tagawa et al. 1988). In addition, the following species were identified in the workshop to be fire tolerant: *Croton argyratus*, *Endospermum peltatum*, *Macaranga gigantea*, *Macaranga pearsonii*, *Macaranga tanarius*, *Mallotus macrostachyus*, *Mallotus muticus*, *Mallotus paniculatus* and *Omphalea bracteata*. All these species are candidates for planting in buffer zones to areas that present a high fire threat.

Recommendations for orangutan reforestation projects

For orangutans, food availability is recognized as a major limiting factor: it largely drives their adaptations, health, reproduction, and behavior. Accordingly, forest enrichment and restoration projects need to address orangutan food needs and preferences. Additional priorities are tree and liana species that provide suitable substrates for arboreal travel, and tree species that local orangutans prefer for nesting.

Orangutans' universal food preference is fruit, especially ripe and fleshy, but they also consume a wide variety of other items including flowers, seeds, leaves (especially young leaves), bark (cambium layer), new shoots (bamboo, palms), invertebrates, honey, fungus, and (rarely) small mammals. Some of these items (notably, bark) serve as fall-back foods (i.e. foods they rely upon when preferred foods are in short supply). The actual species and items they consume vary between sites, and, within one site, between seasons. It is also clear that orangutans feed, by choice, on pioneer as well as climax plant species. At long term research sites, including KNP's northern orangutan habitat, orangutan plant food repertoires average ~50-60, ~100 and ~200 families, genera, and species, respectively (Russon et al., 2009).

Orangutans also show preferences in the species they use for arboreal travel and for nesting. Enrichment or restoration projects will best support orangutans by incorporating these considerations in selecting species to plant. Furthermore, given the importance of Dipterocarpaceae and *Eusideroxylon zwageri* (Ulin, Lauraceae) as preferred trees for nesting purposes, these species also need high priority in reforestation activities in and around KNP.

For most wild orangutan populations, KNP included, the potential for contact and conflict with humans has increased with time and continues to be a major problem. Within the last 3-5 years, several orangutans in the KNP area have been killed or badly injured when they ranged into human-inhabited areas. For this reason, important considerations for forest enrichment and restoration programs are species choices and planting locations that do the most possible to avoid vs. enable orangutan-human contact. Examples include planting any agriculturally important species only in areas known to be inaccessible to orangutans, and planting species important to orangutans in areas that humans are unlikely to access. This would especially be the case for palm-oil and edible fruit species, which should not be planted in close to proximity to KNP forests supporting orangutan.

It is important that a fire management strategy is in place and that the resources are available to implement this immediately. At a monitoring level, satellite-based fire early warning systems detecting active fires (hot spots) and dryness indices provide valuable information for forest managers (Hoffmann et al. 1999). A number of these systems are operational in Indonesia (Dennis 1999).

Udin, a guide at Kutai National Park

Caveats, next steps and future project directions

Our trait based analysis shows that East Kalimantan botany is - with a few exceptions - poorly known in terms of information required to conduct a comprehensive trait based analysis for vulnerability. There is a need to step up research efforts and collect the data required to make informed decisions regarding climate change impacts on Southeast Asian forests. More pragmatic studies are required that can directly clarify conservation needs and/ or opportunities, and more focus on the direct effects of particular threats and on means to address these effects.

The group of Dipterocarps considered in this study consistently demonstrated traits that suggested this group of species has a set of life history characteristics that predispose them to being vulnerable to climate change, both as a function of sensitivity and low adaptive capacity. While large numbers of seeds can be produced, an adaptability trait, Corlett (2009) notes that species of Dipterocarpaceae and Fabaceae will normally only be dispersed distances less than 100 m.

These traits likely apply to most other members of the genera considered here: *Shorea* and *Dipterocarpus*. This is of concern given that distribution modelling aimed at quantifying impacts of climate change on available climate space for two species has shown that future scenarios predict a reduction in available suitable potential range, mostly as a function of changing precipitation patterns (Deb et al. 2017).

The family Dipterocarpaceae comprises approximately 510 species and 16 genera, with 13 genera and 470 species largely restricted to South and Southeast Asia (Appanah and Turnbull 1998). Dipterocarp forests play an important role in the economy of Indonesia and are already heavily threatened by deforestation. Among the 13 genera in South and Southeast Asia, *Shorea* and *Dipterocarpus* are the first and third most diverse genera, respectively. Most species of these two genera are currently listed as threatened in different categories (i.e. 109 and 34 Critically Endangered species for *Shorea* and *Dipterocarpus*, respectively), and at least one species from each genus is now regionally extinct (*Shorea cuspidata* in Malaysia and *Dipterocarpus cinereus* in Indonesia) (Deb et al. 2017).

The presence of people living in the park has yet to be capitalized to the benefit of the national park itself: there is little tourism compared to other destinations where viewing of wild orangutans is possible, no homestays, and very few local guides. Alternative livelihood opportunities that capitalize on biodiversity remain to be widely taken up. Examples include houses for edible-nest swiftlets (*Aerodramus fuciphagus*) and the black-nest swiftlet, (*Aerodramus maximus*), nests of which are used to make birds-nest soup (Hooper 2014). It is beyond the scope of this report to address community conflict issues in the light of threats and opportunities to the national park, but it is worth noting that given the need of mining companies to source seeds and seedlings for restoration efforts, potential exists for community nursery projects.

Orangutan at Prevab

Contributors at the 2018 workshop in Bontang.

Summary of concerns and suggested ways forward emerging from the followup workshop

A follow up workshop was hosted by the IUCN in Bontang, Indonesia, from 6-9 February 2018 to present the results of the trait based vulnerability to climate change workshop held during 2017, and to examine how these results could be implemented through current and future restoration projects. This workshop thus had a stronger restoration theme than the 2017 workshop, and included presentations on forest restoration in KNP, orangutan research in KNP, restoration case study presentations, restoration on mining concessions, and fire management. Round table discussions on the implementation of any restoration activities in and around KNP resulted in a list of key concerns, together with their priority and potential actions (Table 13). A consistent theme raised with each concern (and hence not listed in the table) was the lack of funding to address these concerns, e.g. need for funding for more fire fighting equipment and training.

Other priorities

1. Strengthen collaborations within the workshop group (create a working group).
2. Finding new partners to fill these gaps:
    a. Investigate gaps in silvicultural knowledge
    b. Community engagement - fire management
    c. Tap into corporate and social responsibility commitments to continue reforestation

Table 13. Key Concerns raised about forest restoration in Kutai National Park during the 2018 worksho

Issue	Priority	Next steps
Poor fit of government regulations for E Kalimantan	High	Strengthen the association of forest restoration agencies and discuss criteria and methods*
Availability of seed and source plants for important naturally occurring species	High	Plan for collecting seeds and seedlings from masting species. Work with other nurseries? ** Improve KNP nursery facilities.
Lack of knowledge on silviculture for less commonly used species	Medium	Partner with Dipterocarpa, Mulawarman, Leiden Uni, Balitek Samboja or research institutes.
Fire prevention	Very High	Strengthen collaboration with Manggala Agni and TNI-Polri (armed forces and police) and community. Better education and awareness. Pursue action on offenders.
Monitoring and protection post restoration	Medium/High	Processes are in place. Remember this is important to do. Monitor beyond 3 years: Budget for long-term monitoring (>3 yrs). Ensure auditing process (recording and reporting). Potential research project on success.
Preparations for Climate Change (drier and hotter = drought + more fire)	Low/Medium	Education on plant traits that are resilient to climate change. Educate nursery staff which plants will be required. Plant thinking about El Niño. Climate smart planting regimes.
Training and capacity building	Medium	In-house training. Community out-reach training. Conflict resolution training. Silviculture/nursery training.
Community conflict	High	Involve other community-focused NGOs to implement e.g. BOS Alternative livelihoods programs*** Appoint a community liaisons officer to improve communication and understand the community.
Industry stability (KPC, INDOMINCO lifetimes): implications for community employment	No consensus	Alternative livelihoods programs may cushion unemployment.
Encroachment / Land invasion: investors putting in illegal tenants	Very High	Strengthen relationship between TNK and Gakum. Political / media attention via Tempo. Investigative reporting.

* Approaching government for clarification deemed infeasible.

** Work with communities to collect and grow plants (BOS model)

*** Should tourism be successful in fulfilling its positive and helpful potential, it must be meticulously planned and sustainably managed and one key to this is the support of the host community and successful involvement of stakeholders (Gunn and Var, 2002).

References

Abood, S.A., Lee, J.S.H., Burivalova, Z., Garcia-Ulloa, J. and Koh, L.P. (2015). 'Relative Contributions of the Logging, Fiber, Oil Palm, and Mining Industries to Forest Loss in Indonesia'. *Conservation Letters* 8:58-67.

Abram, N.K., Meijaard, E., Wells, J.A., Ancrenaz, M., Pellier, A.S., Runting, R.K., Gaveau, D., Wich, S., Tjiu, A. and Nurcahyo, A. (2015). 'Mapping perceptions of species' threats and population trends to inform conservation efforts: the Bornean orangutan case study'. *Diversity and Distributions* 21:487-499.

Aldhous, P. (2004). 'Borneo is burning'. *Nature* 432:144-146.

Ancrenaz, M., Gumal, M., Marshall, A.J., Meijaard, E., Wich , S.A. and Husson, S. (2016a). '*Pongo pygmaeus* ssp. *morio*. The IUCN Red List of Threatened Species 2016: e.T63544A17990681. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T63544A17990681.en.' [Accessed 15 November 2017].

Ancrenaz, M., Gumal, M., Marshall, A.J., Meijaard, E., Wich , S.A. and Husson, S. (2016b). '*Pongo pygmaeus*. The IUCN Red List of Threatened Species 2016: e.T17975A17966347. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T17975A17966347.en.' [Accessed 26 April 2018].

Ancrenaz, M., Oram, F., Ambu, L., Lackman, I., Ahmad, E., Elahan, H., Kler, H., Abram, N.K. and Meijaard, E. (2015). 'Of Pongo, palms and perceptions: a multidisciplinary assessment of Bornean orang-utans *Pongo pygmaeus* in an oil palm context'. *Oryx* 49:465-472.

Ansell, F.A., Edwards, D.P. and Hamer, K.C. (2011). 'Rehabilitation of Logged Rain Forests: Avifaunal Composition, Habitat Structure, and Implications for Biodiversity-Friendly REDD+'. *Biotropica* 43:504-511.

Appanah, S. and Turnbull, J.M. (1998). *A Review of Dipterocarps: Taxonomy, Ecology, and Silviculture*. Bogor, Indonesia: Center for International Forestry Research.

Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D. and Houghton, R.A. (2017). 'Tropical forests are a net carbon source based on aboveground measurements of gain and loss'. *Science* 358:230-234.

Böhm, M., Cook, D., Ma, H., Davidson, A.D., García, A., Tapley, B., Pearce-Kelly, P. and Carr, J. (2016). 'Hot and bothered: using trait-based approaches to assess climate change vulnerability in reptiles'. *Biological Conservation* 204:32-41.

Bonal, D., Burban, B., Stahl, C., Wagner, F. and Hérault, B. (2016). 'The response of tropical rainforests to drought—lessons from recent research and future prospects'. *Annals of Forest Science* 73:27-44.

Bonner, M. (2017). '*Restoration of soil microbes and organic matter through tropical reforestation*'. PhD thesis, The University of Queensland, Australia.

Brühl, C.A. and Eltz, T. (2010). 'Fuelling the biodiversity crisis: species loss of ground-dwelling forest ants in oil palm plantations in Sabah, Malaysia (Borneo)'. *Biodiversity and Conservation* 19:519-529.

Campbell, J.L. (1992). '*Ecology of Bornean Orang-Utans (Pongo pygmaeus) in drought-and fire-affected lowland rainforest*'. PhD thesis, Pennsylvania State University, USA.

Caniago, I. and Stephen, F.S. (1998). 'Medicinal plant ecology, knowledge and conservation in Kalimantan, Indonesia'. *Economic Botany* 52:229-250.

Cannon, C.H. and Leighton, M. (2004). 'Tree species distributions across five habitats in a Bornean rain forest'. *Journal of Vegetation Science* 15:257-266.

Carr, J., Outhwaite, W., Goodman, G., Oldfield, T. and Foden, W. (2013). *Vital but vulnerable: climate change vulnerability and human use of wildlife in Africa's Albertine Rift*. Gland, Switzerland: IUCN Species Survival Commission.

Certini, G. (2005). 'Effects of fire on properties of forest soils: a review'. *Oecologia* 143:1-10.

Chadwick, R., Good, P., Martin, G. and Rowell, D.P. (2016). 'Large rainfall changes consistently projected over substantial areas of tropical land'. *Nature Climate Change* 6:177-181.

Charles, L.S., Dwyer, J.M., Smith, T.J., Connors, S., Marschner, P. and Mayfield, M.M. (2018). 'Species wood density and the location of planted seedlings drive early-stage seedling survival during tropical forest restoration'. *Journal of Applied Ecology* 55:1009-1018.

Chazdon, R.L. (2008). 'Beyond deforestation: restoring forests and ecosystem services on degraded lands'. *Science* 320:1458-1460.

Cochrane, M.A. and Schulze, M.D. (1998). 'Forest fires in the Brazilian Amazon'. *Conservation Biology* 12:948-950.

Corlett, R.T. (2009). 'Seed dispersal distances and plant migration potential in tropical East Asia'. *Biotropica* 41:592-598.

Corlett, R.T. (2010). 'Invasive aliens on tropical East Asian islands'. *Biodiversity and Conservation* 19:411-423.

Corlett, R.T. (2016). 'The impacts of droughts in tropical forests'. *Trends in Plant Science* 21:584-593.

Cosset, C.C.P. and Edwards, D.P. (2017). 'The effects of restoring logged tropical forests on avian phylogenetic and functional diversity'. *Ecological Applications* 27:1932-1945.

Cronk, Q.C. and Fuller, J.L. (2014). *Plant invaders: the threat to natural ecosystems*, Routledge, UK: Routledge Press.

Crutchfield, J. (2007). 'Indonesia: Palm oil production prospects continue to grow'. *United States Department of Agriculture, Foreign Agriculture Services, Commodity Intelligence Report*. Available at: https://ipad.fas.usda.gov/highlights/2007/12/indonesia_palmoil/. [Accessed 11 June 2018].

Cushman, S.A., Macdonald, E.A., Landguth, E.L., Malhi, Y. and Macdonald, D.W. (2017). 'Multiple-scale prediction of forest loss risk across Borneo'. *Landscape Ecology* 32:1581–1598.

Daehler, C.C. (2003). 'Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration'. *Annual Review of Ecology, Evolution, and Systematics* 34:183-211.

de Bruyn, M., Stelbrink, B., Morley, R.J., Hall, R., Carvalho, G.R., Cannon, C.H., van den Bergh, G., Meijaard, E., Metcalfe, I. and Boitani, L. (2014). 'Borneo and Indochina are major evolutionary hotspots for Southeast Asian biodiversity'. *Systematic Biology* 63:879-901.

De Groot, R.S., Blignaut, J., Ploeg, S., Aronson, J., Elmqvist, T. and Farley, J. (2013). 'Benefits of investing in ecosystem restoration'. *Conservation Biology* 27:1286-1293.

Deb, J.C., Phinn, S., Butt, N. and McAlpine, C.A. (2017). 'The impact of climate change on the distribution of two threatened Dipterocarp trees'. *Ecology and Evolution* 7:2238-2248.

Dennis, R.A., Mayer, J., Applegate, G., Chokkalingam, U., Colfer, C.J.P., Kurniawan, I., Lachowski, H., Maus, P., Permana, R.P. and Ruchiat, Y. (2005). 'Fire, people and pixels: linking social science and remote sensing to understand underlying causes and impacts of fires in Indonesia'. *Human Ecology* 33:465-504.

Edwards, D.P., Backhouse, A.R., Wheeler, C., Khen, C.V. and Hamer, K.C. (2012). 'Impacts of logging and rehabilitation on invertebrate communities in tropical rainforests of northern Borneo'. *Journal of Insect Conservation* 16:591-599.

Edwards, D.P., Hodgson, J.A., Hamer, K.C., Mitchell, S.L., Ahmad, A.H., Cornell, S.J. and Wilcove, D.S. (2010). 'Wildlife-friendly oil palm plantations fail to protect biodiversity effectively'. *Conservation Letters* 3:236-242.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Brühl, C.A., Donald, P.F. and Phalan, B. (2008). 'How will oil palm expansion affect biodiversity?'. *Trends in Ecology & Evolution* 23:538-545.

Foden, W. and Young, B. (2016). '*IUCN SSC guidelines for assessing species' vulnerability to climate change* Version 1.0. Occasional Paper of the IUCN Species Survival Commission No. 59'. Cambridge, UK and Gland, Switzerland: IUCN Species Survival Commission.

Foden, W.B., Butchart, S.H., Stuart, S.N., Vié, J.-C., Akçakaya, H.R., Angulo, A., DeVantier, L.M., Gutsche, A., Turak, E. and Cao, L. (2013). 'Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals'. *PLOS One* 8:e65427.

García-García, D. and Ummenhofer, C.C. (2015). 'Multidecadal variability of the continental precipitation annual amplitude driven by AMO and ENSO'. *Geophysical Research Letters* 42:526-535.

Garcia, R.A., Cabeza, M., Rahbek, C. and Araújo, M.B. (2014). 'Multiple dimensions of climate change and their implications for biodiversity'. *Science* 344:1247579.

Garrity, D.P., Soekardi, M., Van Noordwijk, M., De La Cruz, R., Pathak, P.S., Gunasena, H.P.M., Van So, N., Huijun, G. and Majid, N.M. (1996). 'The Imperata grasslands of tropical Asia: area, distribution, and typology'. *Agroforestry Systems* 36:3-29.

Gaveau, D.L., Sheil, D., Husnayaen, M.A.S., Arjasakusuma, S., Ancrenaz, M., Pacheco, P. and Meijaard, E. (2016). 'Rapid conversions and avoided deforestation: examining four decades of industrial plantation expansion in Borneo'. *Scientific Reports* 6.

Gaveau, D.L., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N.K., Ancrenaz, M., Nasi, R., Quinones, M. and Wielaard, N. (2014). 'Four decades of forest persistence, clearance and logging on Borneo'. *PLOS One* 9:e101654.

Gilbert, N. (2012). '*Palm-oil boom raises conservation concerns*'. London, England: Macmillan Publishers Ltd.

Gill, V. (2018). '*'100,000 orangutans' killed in 16 years*'. Available at: http://www.bbc.com/news/science-environment-42994630. [Accessed 26 April 2018].

Goldammer, J.G. (2007). 'History of equatorial vegetation fires and fire research in Southeast Asia before the 1997–98 episode: a reconstruction of creeping environmental changes'. *Mitigation and Adaptation Strategies for Global Change* 12:13-32.

Goodland, R.J., Wicks, C. and Doyle, C. (2009). *Philippines: Mining or Food?*, London, UK: Working Group on Mining in the Philippines.

Goossens, B., Setchell, J., James, S., Funk, S., Chikhi, L., Abulani, A., Ancrenaz, M., Lackman-Ancrenaz, I. and Bruford, M.W. (2006). 'Philopatry and reproductive success in Bornean orang-utans (*Pongo pygmaeus*)'. *Molecular Ecology* 15:2577-2588.

Graham, L.L., Giesen, W. and Page, S.E. (2017). 'A common-sense approach to tropical peat swamp forest restoration in Southeast Asia'. *Restoration Ecology* 25:312-321.

Gunn, C.A. and Var, T. (2002). *Tourism planning: Basics, concepts, cases. Fourth Edition*, New York, USA and London, UK, Routledge: Taylor and Francis.

Hall, R. and Holloway, J.D. (1998). *Biogeography and geological evolution of SE Asia*. Leiden, The Netherlands: Backhuys.

Hedges, S. and Meijaard, E. (1999). *Reconnaissance survey for banteng (Bos javanicus) and banteng survey methods training project, Kayan-Mentarang National Park, East Kalimantan, Indonesia*. Indonesia: WWF-Indonesia

Hooper, R. (2014). 'Farming bird's nests for soup on an industrial scale'. *New Scientist* 222:24-25.

IPCC (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (2014). 'Part B: Regional Aspects: Volume 2, Regional Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report'. In: IPCC (ed.) *Climate Change 2014: Impacts, Adaptation and Vulnerability - Contributions of the Working Group II to the Fifth Assessment Report*. Cambridge, UK: Cambridge University Press.

IUCN (in prep). 'Oil palm and biodiversity: A Situation Analysis by the IUCN Oil Palm Task Force'.

Jolly, W.M., Cochrane, M.A., Freeborn, P.H., Holden, Z.A., Brown, T.J., Williamson, G.J. and Bowman, D.M.J.S. (2015). 'Climate-induced variations in global wildfire danger from 1979 to 2013'. *Nature Communications* 6:7537.

Kier, G., Mutke, J., Dinerstein, E., Ricketts, T.H., Kuper, W., Kreft, H. and Barthlott, W. (2005). 'Global patterns of plant diversity and floristic knowledge'. *Journal of Biogeography* 32:1107-1116.

KPC Sustainability Report (2016). *KPC Sustainability Report*, Available at: http://www.kpc.co.id/files/download/file/19/KPC_SR_2016_WebRes.pdf. [Accessed 21 February 2018].

Langner, A. and Siegert, F. (2009). 'Spatiotemporal fire occurrence in Borneo over a period of 10 years'. *Global Change Biology* 15:48-62.

Leighton, M. (1993). 'Modeling dietary selectivity by Bornean orangutans: evidence for integration of multiple criteria in fruit selection'. *International Journal of Primatology* 14:257-313.

Leighton, M. and Wirawan, N. (1984). 'The El Niño Southern Oscillation event in southeast Asia: Effects of drought and fire in tropical forest in eastern Borneo'. *WWF report*:31.

Leighton, M. and Wirawan, N. (1986). 'Catastrophic drought and fire in Borneo tropical rain forest associated with the 1982-83 El Niño Southern Oscillation event'. In: G.T. Prance (ed.) *Tropical rain forest and the world atmosphere*. pp. 75-102. Westview Press, Boulder, Colorado, USA.

Leung, G.P., Hau, B.C. and Corlett, R.T. (2009). 'Exotic plant invasion in the highly degraded upland landscape of Hong Kong, China'. *Biodiversity and Conservation* 18:191.

Lhota, S., Loken, B., Spehar, S., Fell, E., Pospěch, A. and Kasyanto, N. (2012). 'Discovery of Miller's Grizzled Langur (Presbytis hosei canicrus) in Wehea Forest Confirms the Continued Existence and Extends Known Geographical Range of an Endangered Primate'. *American Journal of Primatology* 74:193-198.

Limberg, G., Moeliono, M., Indriatmoko, Y., Iwan, R., Utomo, N., Purwanto, E. and Mulyana, A. (2009). 'Incentives to conserve or convert? Can conservation compete with coal in Kutai National Park, Indonesia?'. *International Journal of Biodiversity Science & Management* 5:190-198.

Mackie, C. (1984). 'The lessons behind East Kalimantan's forest fires'. *Borneo Research Bulletin* 16:63-74.

MacKinnon, K., Hatta, G., Halim, H. and Mangalir, A. (1996). *The ecology of Kalimantan*, Hong Kong: Periplus Editions.

McAlpine, C.A., Johnson, A., Salazar, A., Syktus, J., Wilson, K., Meijaard, E., Seabrook, L., Dargusch, P., Nordin, H. and Sheil, D. (2018). 'Forest loss and Borneo's climate'. *Environmental Research Letters* 13:044009.

McSweeney, C., Rahmat, R., Redmond, G., Marzin, C., Murphy, J., Jones, R., Cheong, W.-K. and Palmer, M. (2013). 'Sub-selection of CMIP5 GCMs for downscaling over Singapore'. *Singapore 2nd National Climate Change Study - Phase 1*. Singapore: Meteorological Service Singapore.

Meijaard, E., Buchori, D., Hadiprakarsa, Y., Utami-Atmoko, S.S., Nurcahyo, A., Tjiu, A., Prasetyo, D., Christie, L., Ancrenaz, M. and Abadi, F. (2011). 'Quantifying killing of orangutans and human-orangutan conflict in Kalimantan, Indonesia'. *PLOS One* 6:e27491.

Meijaard, E., Sheil, D., Nasi, R., Augeri, D., Rosenbaum, B., Iskandar, D., Setyawati, T., Lammertink, M., Rachmatika, I., Wong, A., Soehartono, T., Stanley, S. and O'Brien, T. (2005). *Life after logging: reconciling wildlife conservation and production forestry in Indonesian Borneo*. Bogor, Indonesia: Center for International Forestry Research.

Moeliono, M. and Purwanto, E. (2008). 'A Park in Crisis: local governance and national policy'. *Governing Shared Resources: Connecting Local Experience to Global Challenges, the Twelfth Biennial Conference of the International Association for the Study of Commons, Cheltenham, England: Digital library of the Commons*. Available at https://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/2127/Moeliono_106401.pdf?sequence=1'. [Accessed 14 April 2018].

Moles, A.T., Flores-Moreno, H., Bonser, S.P., Warton, D.I., Helm, A., Warman, L., Eldridge, D.J., Jurado, E., Hemmings, F.A. and Reich, P.B. (2012). 'Invasions: the trail behind, the path ahead, and a test of a disturbing idea'. *Journal of Ecology* 100:116-127.

Mongabay. (2018). *Four Indonesian farmers charged in killing of orangutan that was shot 130 times*. Available at: https://news.mongabay.com/2018/02/four-indonesian-farmers-charged-in-killing-of-orangutan-that-was-shot-130-times/. [Accessed 26 April 2018].

Nater, A., Mattle-Greminger, M.P., Nurcahyo, A., Nowak, M.G., de Manuel, M., Desai, T., Groves, C., Pybus, M., Sonay, T.B. and Roos, C. (2017). 'Morphometric, behavioral, and genomic evidence for a new orangutan species'. *Current Biology* 22:3487-3498.

Nelleman, C., Miles, I., Kaltenborn, B.P., Virtue, M. and Ahlenius, H. (2007). *The last stand of the orangutan: state of emergency: illegal logging, fire and palm oil in Indonesia's national parks*. Arendal, Norway: United Nations Environment Programme, GRID.

Osunkoya, O.O., Othman, F.E. and Kahar, R.S. (2005). 'Growth and competition between seedlings of an invasive plantation tree, *Acacia mangium*, and those of a native Borneo heath-forest species, *Melastoma beccarianum*'. *Ecological Research* 20:205-214.

Pacifici, M., Foden, W.B., Visconti, P., Watson, J.E., Butchart, S.H., Kovacs, K.M., Scheffers, B.R., Hole, D.G., Martin, T.G. and Akcakaya, H.R. (2015). 'Assessing species vulnerability to climate change'. *Nature Climate Change* 5:215.

Padmanaba, M. and Sheil, D. (2014). 'Spread of the invasive alien species *Piper aduncum* via logging roads in Borneo'. *Tropical Conservation Science* 7:35-44.

Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A. and Limin, S. (2002). 'The amount of carbon released from peat and forest fires in Indonesia during 1997'. *Nature* 420:61-65.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L. and Canadell, J.G. (2011). 'A large and persistent carbon sink in the world's forests'. *Science* 333:988-993.

Peluso, N.L. (1992). 'The political ecology of extraction and extractive reserves in East Kalimantan, Indonesia'. *Development and Change* 23:49-74.

Pendall, E., Bridgham, S., Hanson, P.J., Hungate, B., Kicklighter, D.W., Johnson, D.W., Law, B.E., Luo, Y., Megonigal, J.P. and Olsrud, M. (2004). 'Below-ground process responses to elevated CO2 and temperature: a discussion of observations, measurement methods, and models'. *New Phytologist* 162:311-322.

Phillips, O.L., Van Der Heijden, G., Lewis, S.L., López-González, G., Aragão, L.E., Lloyd, J., Malhi, Y., Monteagudo, A., Almeida, S. and Dávila, E.A. (2010). 'Drought–mortality relationships for tropical forests'. *New Phytologist* 187:631-646.

PHVA (ed.) (2017). *Orangutan Population and Habitat Viability Assessment: Final Report*. Apple Valley, MN: IUCN/SSC Conservation Breeding Specialist Group.

Potts, M.D., Ashton, P.S., Kaufman, L.S. and Plotkin, J.B. (2002). 'Habitat patterns in tropical rain forests: a comparison of 105 plots in northwest Borneo'. *Ecology* 83:2782-2797.

PT Bumi Resources. (2017). *PT BUMI Resources Annual Public Expose*. Available at http://www.bumiresources.com/index.php?option=com_financialinfo&task=download&id=606&Itemid=115. [Accessed 21 February 2018].

Putz, F. and Redford, K. (2009). 'Dangers of carbon-based conservation'. *Global Environmental Change* 19:400-401.

Putz, F.E., Blate, G.M., Redford, K.H., Fimbel, R. and Robinson, J. (2001). 'Tropical forest management and conservation of biodiversity: an overview'. *Conservation Biology* 15:7-20.

PWC (2017). *Mining in Indonesia. Investment and Taxation Guide. May 2017 - 9th Edition*. Price Waterhouse Coopers. Available at https://www.pwc.com/id/en/energy-utilities-mining/assets/mining/mining-guide-2017-web.pdf. [Accessed 15 April 2018].

Qian, J.-H., Robertson, A.W. and Moron, V. (2013). 'Diurnal cycle in different weather regimes and rainfall variability over Borneo associated with ENSO'. *Journal of Climate* 26:1772-1790.

Reside, A.E., Butt, N. and Adams, V.M. (2017). 'Adapting systematic conservation planning for climate change'. *Biodiversity and Conservation* 27:1-29.

Rijksen, H.D. and Meijaard, E. (1999). *Our vanishing relative. The status of wild orang-utans at the close of the twentieth century*. Wageningen, The Netherlands: The Tropenbos Foundation.

Rodman, P.S. (1973). 'Population composition and adaptive organisation among orangutans of the Kutai Reserve'. In: R. Michael and J. Crook (eds.) *Comparative ecology and behaviour of primates*. pp. 171-209. London, UK: Academic Press.

Rodman, P.S. (1977). 'Feeding behaviour of orang-utans of the Kutai Nature Reserve, East Kalimantan'. In: T. Clutton-Brock (ed.) *Primate ecology: studies of feeding and ranging behaviour in Lemurs Monkeys and Apes*. pp. 383–413. New York, USA: Academic Press.

Ropelewski, C.F. and Halpert, M.S. (1996). 'Quantifying southern oscillation-precipitation relationships'. *Journal of Climate* 9:1043-1059.

Rowland, L., da Costa, A.C.L., Galbraith, D.R., Oliveira, R., Binks, O.J., Oliveira, A., Pullen, A., Doughty, C., Metcalfe, D. and Vasconcelos, S. (2015). 'Death from drought in tropical forests is triggered by hydraulics not carbon starvation'. *Nature* 528:119-122.

Russell, C.L. and Ankenman, M. (1996). 'Orangutans as photographic collectibles: ecotourism and the commodification of nature'. *Tourism Recreation Research* 21:71-78.

Russon, A.E., Kuncoro, P. and Ferisa, A. (2015). 'Orangutan behavior in Kutai National Park after drought and fire damage: Adjustments to short-and long-term natural forest regeneration'. *American Journal of Primatology* 77:1276-1289.

Russon, A.E., Wich, S.A., Ancrenaz, M., Kanamori, T., Knott, C.D., Kuze, N., Morrogh-Bernard, H.C., Pratje, P., Ramlee, H. and Rodman, P. (2009). 'Geographic variation in orangutan diets'. In: S.A. Wich, S.S. Utami Atmoko, T. Mitra Setia and C.P. van Schaik (eds.) *Orangutans: Geographic Variation in Behavioral Ecology*. pp. 135-156. Oxford, UK: Oxford University Press.

Santika, T., Ancrenaz, M., Wilson, K.A., Spehar, S., Abram, N., Banes, G.L., Campbell-Smith, G., Curran, L., d'Arcy, L. and Delgado, R.A. (2017). 'First integrative trend analysis for a great ape species in Borneo'. *Scientific Reports* 7:4839.

Sawitri, R. and Adalina, Y. (2016). 'Kajian Usulan Zona Khusus Taman Nasional Kutai'. *Jurnal Penelitian Hutan dan Konservasi Alam* 13:85-100.

Scheffers, B.R., De Meester, L., Bridge, T.C., Hoffmann, A.A., Pandolfi, J.M., Corlett, R.T., Butchart, S.H., Pearce-Kelly, P., Kovacs, K.M. and Dudgeon, D. (2016). 'The broad footprint of climate change from genes to biomes to people'. *Science* 354:aaf7671.

Sheil, D. (2018). 'Forests, atmospheric water and an uncertain future: the new biology of the global water cycle'. *Forest Ecosystems* 5:19.

Sheil, D., Casson, A., Meijaard, E., Van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., Wertz, K. and Kanninen, M. (2009). *The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?*, Bogor, Indonesia: Center for International Forestry Research.

Shoo, L.P., Hoffmann, A.A., Garnett, S., Pressey, R.L., Williams, Y.M., Taylor, M., Falconi, L., Yates, C.J., Scott, J.K. and Alagador, D. (2013). 'Making decisions to conserve species under climate change'. *Climatic Change* 119:239-246.

Siegert, F., Ruecker, G., Hinrichs, A. and Hoffmann, A. (2001). 'Increased damage from fires in logged forests during droughts caused by El Nino'. *Nature* 414:437-440.

Slik, J., Poulsen, A., Ashton, P., Cannon, C., Eichhorn, K., Kartawinata, K., Lanniari, I., Nagamasu, H., Nakagawa, M. and Van Nieuwstadt, M. (2003). 'A floristic analysis of the lowland dipterocarp forests of Borneo'. *Journal of Biogeography* 30:1517-1531.

Sloan, S., Locatelli, B., Wooster, M.J. and Gaveau, D.L. (2017). 'Fire activity in Borneo driven by industrial land conversion and drought during El Niño periods, 1982–2010'. *Global Environmental Change* 47:95-109.

Smits, W.T.M. (1994). '*Dipterocarpaceae: mycorrhizae and regeneration*'. PhD thesis.: Wageningen Agricultural University, The Netherlands.

Society for Ecological Restoration International Science & Policy Working Group (2004). 'The SER International Primer on Ecological Restoration'. www.ser.org, Tucson: Society for Ecological Restoration International.

Soepadmo, E., Saw, L. and Chung, R. (2004). *Tree flora of Sabah and Sarawak: Volume 5*, Selangor Darul Ehsan, Malaysia: Forest Research Institute Malaysia (FRIM).

Stadtmueller, T. (1990). *Soil erosion in east Kalimantan, Indonesia*. Proceedings of the Fiji Symposium. IAHS-AISH 192:221-230.

Stocker, D.Q. (2013). *Climate change 2013: The physical science basis*. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers, IPCC.

Struebig, M.J., Wilting, A., Gaveau, D.L., Meijaard, E., Smith, R.J., Fischer, M., Metcalfe, K., Kramer-Schadt, S. and Consortium, B.M.D. (2015). 'Targeted conservation to safeguard a biodiversity hotspot from climate and land-cover change'. *Current Biology* 25:372-378.

Supari, Tangang, F., Juneng, L. and Aldrian, E. (2017). 'Observed changes in extreme temperature and precipitation over Indonesia'. *International Journal of Climatology* 37:1979-1997.

Suzuki, A. (1984). 'The socio-ecological study on orangutans in Kutai Nature Reserve of East Kalimantan, Indonesia'. *Kyoto University Overseas Research Report of Studies on Asian Non-Human Primates*:67-76.

Suzuki, A. (1986). 'The socio-ecological study on the orangutan in the Mentoko-BT Sinara Study Area'. *Kutai National Park, East Kalimantan. In: Kyoto University Overseas Research Report of Studies on Asia non-human primates*:23-28.

Tagawa, H., Suzuki, E., Wirawan, N., Miyagi, Y. and Oka, N.P. (1988). 'Change of vegetation in Kutai National Park, East Kalimantan'. *Kagoshima University Occasional Papers* 14:12-50.

Takahashi, A., Kumagai, T.o., Kanamori, H., Fujinami, H., Hiyama, T. and Hara, M. (2017). 'Impact of Tropical Deforestation and Forest Degradation on Precipitation over Borneo Island'. *Journal of Hydrometeorology* 18:2907-2922.

Teo, D.H., Tan, H.T., Corlett, R.T., Wong, C.M. and Lum, S.K. (2003). 'Continental rain forest fragments in Singapore resist invasion by exotic plants'. *Journal of Biogeography* 30:305-310.

TNK (2016). *Statistik: Taman Nasional Kutai, Tahun 2016.* Bontang, Kalimantan Timur, Indonesia: Balai Taman Nasional Kutai.

Tong, X., Brandt, M., Yue, Y., Horion, S., Wang, K., De Keersmaecker, W., Tian, F., Schurgers, G., Xiao, X. and Luo, Y. (2018). 'Increased vegetation growth and carbon stock in China karst via ecological engineering'. *Nature Sustainability* 1:44-50.

Uriarte, M., Schwartz, N., Powers, J.S., Marín-Spiotta, E., Liao, W. and Werden, L.K. (2016). 'Impacts of climate variability on tree demography in second growth tropical forests: the importance of regional context for predicting successional trajectories'. *Biotropica* 48:780-797.

van Nieuwstadt, M.G.L. and Sheil, D. (2005). 'Drought, fire and tree survival in a Borneo rain forest, East Kalimantan, Indonesia'. *Journal of Ecology* 93:191-201.

van Schaik, C.P., Marshall, A.J. and Wich, S.A. (2009). 'Geographic variation in orangutan behavior and biology: : its functional interpretation and its mechanistic basis'. In: S.A. Wich, S.S. Utami-Atmoko, T. Mitra Setia and C.P. van Schaik (eds.). *Orangutans: Geographic variation in behavioral ecology and conservation*. pp. 351-361. Oxford, UK: Oxford University Press.

Vayda, A.P. and Sahur, A. (1996). *Bugis settlers in East Kalimantan's Kutai National Park: Their past and present and some possibilities for their future*. Jakarta, Indonesia: Center for International Forestry Research.

Voigt, M., Wich, S.A., Ancrenaz, M., Meijaard, E., Abram, N., Banes, G.L., Campbell-Smith, G., d'Arcy, L.J., Delgado, R.A., Erman, A., Gaveau, D., Goossens, B., Heinicke, S., Houghton, M., Husson, S.J., Leiman, A., Sanchez, K.L., Makinuddin, N., Marshall, A.J., Meididit, A., Miettinen, J., Mundry, R., Musnanda, Nardiyono, Nurcahyo, A., Odom, K., Panda, A., Prasetyo, D., Priadjati, A., Purnomo, Rafiastanto, A., Russon, A.E., Santika, T., Sihite, J., Spehar, S., Struebig, M., Sulbaran-Romero, E., Tjiu, A., Wells, J., Wilson, K.A. and Kühl, H.S. (2018). 'Global demand for natural resources eliminated more than 100,000 Bornean Orangutans'. *Current Biology* 10.1016/j.cub.2018.01.053.

Wheeler, C.E., Omeja, P.A., Chapman, C.A., Glipin, M., Tumwesigye, C. and Lewis, S.L. (2016). 'Carbon sequestration and biodiversity following 18years of active tropical forest restoration'. *Forest Ecology and Management* 373:44-55.

Whitmore, T.C. (1992). *An introduction to Tropical Rainforests*. Oxford, UK: Clarendon Press.

Whitten, T., van Dijk, P.P., Curran, L., Meijaard, E., Supriatna, J. and Ellis, S. (2004). 'Sundaland'. In: R.A. Mittermeier, P.R. Gil, M. Hoffmann, J. Pilgrim, T. Brooks, C.G. Mittermeier, J. Lamoreux, G.A.B. da Fonseca (eds.). *Hotspots revisited. Earth's biologically richest and most endangered terrestrial ecoregions*, pp.164-172. Mexico: Cemex.

Wich, S.A., Atmoko, S.S.U., Setia, T.M. and Van Schaik, C.P. (2010). *Orangutans: geographic variation in behavioral ecology and conservation*. Oxford, UK: Oxford University Press.

Wich, S.A., Gaveau, D., Abram, N., Ancrenaz, M., Baccini, A., Brend, S., Curran, L., Delgado, R.A., Erman, A. and Fredriksson, G.M. (2012). 'Understanding the Impacts of Land-Use Policies on a Threatened Species: Is There a Future for the Bornean Orang-utan?'. *PLOS One* 7:e49142.

Wich, S.A., Meijaard, E., Marshall, A.J., Husson, S., Ancrenaz, M., Lacy, R.C., van Schaik, C.P., Sugardjito, J., Simorangkir, T. and Traylor-Holzer, K. (2008). 'Distribution and conservation status of the orang-utan (*Pongo* spp.) on Borneo and Sumatra: how many remain?'. *Oryx* 42:329-339.

Wills, J., Herbohn, J., Moreno, M.O.M., Avela, M.S. and Firn, J. (2017). 'Next-generation tropical forests: reforestation type affects recruitment of species and functional diversity in a human-dominated landscape'. *Journal of Applied Ecology* 54:772-783.

Young, B.E., Dubois, N.S. and Rowland, E.L. (2015). 'Using the Climate Change Vulnerability Index to inform adaptation planning: lessons, innovations, and next steps'. *Wildlife Society Bulletin* 39:174-181.

Appendix 1: Species list

A list of the 247 species considered for this report on the vulnerability of plant species used by orangutans in KNP to climate change. Local names were provided at the workshop, and may have Indonesian or Bugis origin. Orang food is the orangutan food score from 0 to 2, where 0 is not used, and 2 is a preferred food in KNP; CCVA is a climate change vulnerability score, with plants with negative scores resilient to CC, with high positive scores indicating vulnerability; NB is the regional importance score (ranging from -1 for pest species, to 5 being of highest importance ecologically, economically); Uncertainty is the sum of traits scored as 'unknown' and ranges from 1 (indicating confidence in the CCV score) to 10 (indicating low confidence in the CCV score). The full file with all traits as completed at the workshop is available as on-line supplementary information. The primary naming authority was the World Checklist of Selected Plant Families: Royal Botanic Gardens, Kew (wcsp.science.kew.org) and Kew's in-development AtoZ, followed by The Plant List (www.theplantlist.org).

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Alpinia ligulata	Kedapat	Zingiberaceae	0	-5	2	1
Alpinia galanga	Lengkuas	Zingiberaceae	0.5	-2	1	2
Amomum compactum	Tete	Zingiberaceae	0	-2	3	2
Etlingera coccinea	Petiti	Zingiberaceae	0	-2	1	2
Tetrastigma rafflesiae		Vitaceae	0	2	1	4
Tetrastigma pedunculare		Vitaceae	1.5	2	1	4
Lantana camara	Bunga tai ayam	Verbenaceae	0	-5	-1	1
Dendrocnide elliptica	Jelatang	Urticaceae	1	-2	1	3
Octomeles sumatrana	Binuang	Tetramelaceae	1	-2	1	3
Solanum sp.	Terung pipit	Solanaceae	0	-6	-1	1
Lygodium circinatum	Pakis hutan	Schizaeacaceae	0	-6	0	1
Donella lanceolata	Kayu pulut	Sapotaceae	0	0	1	4
Palaquium stenophyllum	Nyatoh	Sapotaceae	0	-1	3	3
Dimocarpus longan	Longan	Sapindaceae	1.5	-2	3	3
Mischocarpus pentapetalus	Katan	Sapindaceae	0	-2	2	2
Nephelium ramboutan-ake	Meritam	Sapindaceae	1.5	-2	3	3
Paranephelium xestophyllum	Katan	Sapindaceae	0	-2	2	2
Pometia pinnata	Paku rantau, Matoa	Sapindaceae	1.5	0	3	2
Melicope glabra	Sampang	Rutaceae	1	-1	1	1
Melicope lunu-ankenda	Sampang	Rutaceae	0	0	1	2
Neolamarckia cadamba	Larang	Rubiaceae	0.5	-2	0	3
Nauclea subdita	Bankal kuning	Rubiaceae	1.5	-2	0	2
Uncaria gambir	Gambier	Rubiaceae	0	-2	0	3

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Drypetes longifolia		Putranjivaceae	1.5	-1	1	5
Imperata cylindrica	Alang-alang	Poaceae	0	-6	-1	1
Piper aduncum	Kayu sirih	Piperaceae	0.5	-6	-1	1
Glochidion zeylanicum var. arborescens		Phyllanthaceae	0	-4	0	4
Aporosa lucida		Phyllanthaceae	1.5	-2	1	5
Aporosa subcaudata		Phyllanthaceae	1.5	-2	1	5
Baccaurea costulata		Phyllanthaceae	1.5	0	2	5
Baccaurea macrocarpa		Phyllanthaceae	0.5	-1	3	5
Baccaurea angulata		Phyllanthaceae	0.5	-1	2	5
Baccaurea stipulata		Phyllanthaceae	0.5	-1	2	5
Baccaurea sanguinea		Phyllanthaceae	0	-1	2	5
Baccaurea parviflora		Phyllanthaceae	0.5	-1	2	5
Baccaurea polyneura	Jentikan	Phyllanthaceae	0	0	2	5
Baccaurea pyriformis		Phyllanthaceae	1.5	0	2	5
Baccaurea odoratissima		Phyllanthaceae	0	0	2	5
Chaetocarpus castanocarpus	Lurangan	Peraceae	1.5	-2	1	3
Passiflora foetida	Kelubut	Passifloraceae	0	-5	-1	1
Dendrobium anosmum	Anggrek	Orchidaceae	0	1	3	5
Syzygium leptostemon	Jambu-jambu	Myrtaceae	0	-1	2	4
Syzygium tawahense	Jambu-jambu	Myrtaceae	1.5	0	2	3
Knema latericia	Pala-palaan	Myristicaceae	1.5	-1	2	3
Antiaris toxicaria	Upas	Moraceae	1.5	-1	2	2
Artocarpus anisophyllus	Terap ikal, Keladang	Moraceae	1.5	-1	1	3
Artocarpus integer	Cempadak	Moraceae	0	0	3	3
Artocarpus dadah	Terap, nangka hutan	Moraceae	0	-1	1	5
Artocarpus elasticus	Terap	Moraceae	0.5	-1	2	4
Artocarpus glaucus	Keledang, kledang	Moraceae	0	-1	1	5
Artocarpus kemando		Moraceae	0.5	-1	1	5
Artocarpus lanceifolius		Moraceae	0	-1	1	4
Artocarpus odoratissimus	Terap, benturung	Moraceae	1.5	0	1	5
Artocarpus tamaran	Terap	Moraceae	0.5	0	1	5
Ficus acamptophylla		Moraceae	1.5	0	2	5
Ficus albipila	Beringin putih	Moraceae	1.5	0	2	5
Ficus annulata	Ara	Moraceae	0.5	0	2	5
Ficus aurita	Ara	Moraceae	0	0	2	5

Name	**Local name**	**Family**	**Orang food**	**CCVA**	**NB**	**Uncertainty**
Ficus beccarii		Moraceae	0	0	2	5
Ficus benguetensis		Moraceae	0	0	2	5
Ficus benjamina	Beringin	Moraceae	1.5	0	2	5
Ficus binnendijkii		Moraceae	1.5	0	2	5
Ficus caulocarpa		Moraceae	0	0	2	5
Ficus cereicarpa		Moraceae	0	1	2	5
Ficus crassiramea		Moraceae	1.5	0	2	5
Ficus excavata		Moraceae	1.5	0	2	5
Ficus fistulosa	Ara	Moraceae	0	0	2	5
Ficus grossularioides		Moraceae	0.5	0	2	5
Ficus pumila		Moraceae	0	0	2	5
Ficus heteropleura		Moraceae	0.5	0	2	5
Ficus microcarpa	Bonsai	Moraceae	0.5	0	2	5
Ficus microsyce		Moraceae	0	0	2	5
Ficus obscura		Moraceae	1.5	0	2	5
Ficus ribes		Moraceae	0	0	2	5
Ficus sagittata		Moraceae	1.5	0	2	5
Ficus sundaica	Ara	Moraceae	1.5	0	2	5
Ficus crassiramea subsp. Stupenda		Moraceae	0	0	2	5
Ficus subulata		Moraceae	1.5	0	2	5
Ficus sumatrana		Moraceae	1.5	0	2	5
Ficus trichocarpa		Moraceae	1.5	0	2	5
Ficus recurva var. pedicellata		Moraceae	0	0	2	5
Ficus variegata	Nyawai	Moraceae	1.5	0	2	5
Ficus villosa		Moraceae	1.5	0	2	5
Ficus ingens		Moraceae	0	0	2	5
Parartocarpus bracteata		Moraceae	0.5	0	2	5
Ficus obpyramidata	Ara gendang	Moraceae	2	-1	1	2
Aglaia odoratissima	Lantupak, situr gajah	Meliaceae	1.5	-2	1	3
Aglaia tomentosa	Bunau, kumpang penjaru	Meliaceae	1.5	-2	1	3
Chisocheton ceramicus	Lantupak	Meliaceae	0	-2	1	3
Sandoricum koetjape	Kecapi, ketapi, sental hutan	Meliaceae	0.5	-2	2	3
Walsura pinnata		Meliaceae	0	-1	1	3
Melastoma malabathricum	Karamunting	Melastomataceae	0.5	-6	-1	1

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Clidemia hirta	Harendong bulu	Melastomataceae	0.5	-6	-1	1
Donax canniformis	Bamban	Marantaceae	0.5	-1	1	4
Stachyphrynium borneensis	Lirik beruang	Marantaceae	0	0	0	3
Boschia griffithii	Durian burung	Malvaceae	0	-1	2	3
Durio dulcis	Lahung	Malvaceae	1.5	0	4	3
Durio kutejensis	Lai	Malvaceae	0.5	0	3	3
Durio lanceolatus		Malvaceae	1.5	0	2	3
Durio oxleyanus	Kerantungan	Malvaceae	1.5	-1	4	3
Colona serratifolia		Malvaceae	0	-3	0	3
Pterospermum diversifolium	Bayur	Malvaceae	0	-1	0	3
Kleinhovia hospita	Tahongai, mangar	Malvaceae	2	-4	0	2
Pterospermum javanicum	Bayur	Malvaceae	1.5	-1	1	2
Sterculia rubiginosa	Kayu tebu	Malvaceae	0.5	-2	1	3
Pentace laxiflora	Pose	Malvaceae	0	-2	3	2
Urena lobata		Malvaceae	0	-6	-1	1
Magnolia tsiampacca	Arau	Magnoliaceae	0	0	5	10
Nephrolepis sp.	Pakis hutan	Lomariopsidaceae	0	-6	0	1
Strychnos ignatii	Akar meron	Loganiaceae	0.5	-1	0	7
Strychnos lucida	Akar meron	Loganiaceae	0.5	-1	0	7
Strychnos polytrichantha	Akar meron	Loganiaceae	1.5	0	0	7
Strychnos villosa	Akar meron	Loganiaceae	0.5	-1	0	7
Leea indica	Temali laki	Leeaceae	0.5	-1	0	3
Leea rubra	Temali bini	Leeaceae	0	-1	0	3
Actinodaphne glabra	Medang sahung	Lauraceae	0	-1	3	4
Alseodaphne elmeri	Medang	Lauraceae	0	0	1	4
Beilschmiedia dictyoneura		Lauraceae	0	-1	1	4
Eusideroxylon zwageri	Ulin	Lauraceae	1.5	2	5	3
Litsea angulata	Medang	Lauraceae	0	-1	1	4
Nothaphoebe umbelliflora		Lauraceae	0	-1	2	4
Callicarpa pentandra	Nayup	Lamiaceae	2	-1	0	4
Vitex pinnata	Laban	Lamiaceae	1.5	-2	1	3
Irvingia malayana	Kayu batu	Irvingiaceae	1.5	-1	4	4
Phytocrene racemosa	None	Icacinaceae	1.5	0	0	4
Cratoxylum sumatranum	Gerunggang	Hypericaceae	0	-4	1	2
Gnetum cuspidatum	None	Gnetaceae	1.5	0	1	6

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Adenanthera pavonina	Saga	Fabaceae	1.5	0	1	6
Fordia splendidissima	Tuba-tuba	Fabaceae	0.5	-4	0	4
Intsia palembanica	Merbau	Fabaceae	1.5	1	4	4
Sindora coriacea	Anggi	Fabaceae	1.5	1	5	4
Spatholobus maingayi	Ubar	Fabaceae	0	-1	0	3
Spatholobus oblongifolius	Ubar	Fabaceae	0	0	0	3
Acacia mangium	Akasia	Fabaceae	0	-5	-1	1
Spatholobus sp.	Akar ubar	Fabaceae	1	-6	0	1
Archidendron havilandii	Jengkol hutan	Fabaceae	1	-2	1	3
Parkia speciosa	Pete, petai	Fabaceae	0.5	-2	4	3
Pithecellobium lobatum	Jering hantu	Fabaceae	0	-2	1	3
Croton argyratus	Malakapur, markapur	Euphorbiaceae	1.5	-4	0	2
Endospermum peltatum	Sumpalabu	Euphorbiaceae	1.5	-4	0	2
Macaranga gigantea	Kubung	Euphorbiaceae	1.5	-4	2	2
Macaranga pearsonii	Mahang	Euphorbiaceae	1.5	-3	1	2
Macaranga tanarius	Mahang	Euphorbiaceae	0.5	-4	1	2
Mallotus macrostachyus	Murup	Euphorbiaceae	0	-4	1	2
Mallotus muticus	Murup	Euphorbiaceae	0.5	0	1	5
Mallotus paniculatus	Murup	Euphorbiaceae	0	-4	1	2
Omphalea bracteata		Euphorbiaceae	1.5	-4	0	2
Macaranga sp.	Mahang	Euphorbiaceae	0	-6	0	1
Mallotus spp.	Murup	Euphorbiaceae	0	-6	0	1
Homalanthus populneus	Buta- buta lalat	Euphorbiaceae	0	-6	1	1
Diospyros borneensis	Arang	Ebenaceae	0.5	-2	3	5
Diospyros macrophylla	Baleu	Ebenaceae	1.5	-2	2	5
Dipterocarpus verrucosus	Keruing	Dipterocarpaceae	0	4	5	1
Shorea ferruginea	Meranti merah	Dipterocarpaceae	0	6	5	1
Shorea inappendiculata	Meranti	Dipterocarpaceae	0	5	5	1
Shorea johorensis	Meranti kenuar	Dipterocarpaceae	0	5	5	1
Shorea leprosula	Nyerakat	Dipterocarpaceae	1.5	5	5	1
Shorea pauciflora	Meranti merah	Dipterocarpaceae	0	5	5	1
Shorea polyandra	Pakit	Dipterocarpaceae	1.5	6	5	1
Shorea ovalis	Meranti merah	Dipterocarpaceae	0.5	1	5	1
Hopea mengerawan	Merawan	Dipterocarpaceae	0	0	5	1
Hopea rudiformis	Merawan	Dipterocarpaceae	0	1	5	1

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Dioscorea sp.	Akar gadung	Dioscoreaceae	0	-6	0	1
Dillenia borneensis	Simpur laki	Dilleniaceae	1.5	0	2	6
Dillenia excelsa	Maligara, simpur laki	Dilleniaceae	1.5	-1	4	5
Dillenia reticulata	Simpur	Dilleniaceae	2	-2	0	6
Alangium hirsutum	Sahang sahang	Cornaceae	2	2	0	2
Alangium ridleyi	Laji kuning	Cornaceae	1.5	-1	1	2
Merremia mammosa	Akar belaran	Convolvulaceae	2	-3	0	3
Merremia peltata	Akar belaran	Convolvulaceae	0	-6	0	1
Terminalia catappa	Ketapang	Combretaceae	0.5	0	0	4
Terminalia foetidissima		Combretaceae	1.5	-1	1	5
Garcinia dulcis	Manggis	Clusiaceae	0.5	-1	2	5
Parinari canarioides		Chrysobalanaceae	1.5	0	1	5
Trema tomentosa		Cannabaceae	0	-6	0	1
Trema cannabina		Cannabaceae	0	-2	0	3
Canarium littorale	Kenari	Burseraceae	0.5	-1	2	2
Dacryodes rostrata	Ampadu kalui	Burseraceae	1.5	-1	2	2
Santiria oblongifolia	Asem gerunggang	Burseraceae	1.5	-1	2	2
Scutinanthe brunnea		Burseraceae	1.5	-1	1	2
Spathodea campanulata		Bignoniaceae	0	-5	-1	1
Eupatorium inulaefolium		Asteraceae	0	-6	-1	1
Wedelia biflora		Asteraceae	0	-5	-1	1
Ageratum conyzoides		Asteraceae	0	-6	-1	1
Mikania scandens		Asteraceae	0	-6	-1	1
Vernonia arborea	Tepung-tepung	Asteraceae	0	0	0	3
Asplenium nidus	Sarang burung, ketapa	Aspleniaceae	0.5	2	2	2
Borassodendron borneense	Bendang	Arecaceae	0	3	4	3
Korthalsia spp.	Rotan	Arecaceae	1	-2	3	4
Daemonorops spp.	Rotan	Arecaceae	0	-2	3	4
Alstonia macrophylla	Pulai	Apocynaceae	0	-2	3	4
Alstonia scholaris	Pulai	Apocynaceae	0.5	-2	3	4
Willughbeia angustifolia	Akar jitan	Apocynaceae	0.5	-1	0	4
Willughbeia coriacea	Akar jitan	Apocynaceae	0	-1	0	4
Alstonia angustifolia	Pulai	Apocynaceae	0.5	-2	4	2
Tabernaemontana macrocarpa	Peler kambing	Apocynaceae	0	0	0	2
Artabotrys speciosus	Akar kait	Annonaceae	0	0	0	5

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Artabotrys suaveolens	Akar cenana	Annonaceae	0.5	0	0	5
Cananga odorata	Kenanga	Annonaceae	1.5	-1	3	5
Cyathocalyx sumatranus		Annonaceae	0	0	1	5
Uvaria griffithii	Akar pemadam (?)	Annonaceae	0	0	0	5
Desmos chinensis	Kenanga hutan	Annonaceae	0	0	0	5
Friesodielsia cuneiformis		Annonaceae	0	0	0	5
Goniothalamus macrophyllus	Kayu tapu	Annonaceae	0	1	1	5
Goniothalamus ridleyi	Mempisang	Annonaceae	0	1	1	5
Neo-uvaria acuminatissima	Pisang-pisang	Annonaceae	0.5	0	1	5
Mitrella kentia		Annonaceae	0	0	1	5
Fissistigma manubriatum		Annonaceae	0.5	0	1	5
Mezzettia umbellata	Jerenjang gunung	Annonaceae	0.5	1	2	5
Mitrephora heyneana		Annonaceae	0	0	1	5
Monocarpia euneura		Annonaceae	0.5	1	1	5
Polyalthia cauliflora	Jerenjang	Annonaceae	0.5	0	1	5
Polyalthia borneensis	Jerenjang	Annonaceae	0	1	1	5
Monoon glabrum	Jerenjang	Annonaceae	0	0	1	5
Polyalthia elliptica	Jerenjang	Annonaceae	0	0	1	5
Polyalthia insignis	Jerenjang	Annonaceae	0	0	1	5
Monoon lateriflorum	Ampunyit	Annonaceae	0	0	1	5
Monoon borneense	Jerenjang	Annonaceae	0	1	2	5
Polyalthia oblonga	Jerenjang	Annonaceae	0	0	1	5
Huberantha rumphii	Jerenjang	Annonaceae	0	0	1	5
Polyalthia spathulata	Jerenjang	Annonaceae	0	0	1	5
Maasia sumatrana	Banitan	Annonaceae	0	0	1	5
Popowia pisocarpa		Annonaceae	0.5	0	1	5
Pseuduvaria reticulata		Annonaceae	0	0	1	5
Miliusa horsfieldii		Annonaceae	0	0	1	5
Sageraea lanceolata	Pisang-pisang	Annonaceae	0	0	1	5
Uvaria monticola		Annonaceae	0	0	0	5
Uvaria curtisii		Annonaceae	0	0	0	5
Xylopia ferruginea	Jangkang	Annonaceae	0	0	1	5
Xylopia malayana		Annonaceae	1.5	0	1	5
Anisophyllea disticha		Anisophylleaceae	0	1	2	5
Bouea oppositifolia	Ramania	Anacardiaceae	0.5	0	3	4

Name	Local name	Family	Orang food	CCVA	NB	Uncertainty
Buchanania arborescens	Terentang ayam	Anacardiaceae	0	0	2	4
Dracontomelon costatum	Sengkuang	Anacardiaceae	1.5	-1	3	4
Dracontomelon dao	Sengkuang	Anacardiaceae	2	-1	4	4
Gluta renghas	Rengas tembaga	Anacardiaceae	0.5	1	3	4
Gluta wallichii	Rengas	Anacardiaceae	1.5	0	3	4
Koordersiodendron pinnatum	Tebu hitam	Anacardiaceae	1.5	-1	2	4
Mangifera caesia	Wanyi	Anacardiaceae	0.5	1	4	4
Mangifera foetida	Asam bawang	Anacardiaceae	0.5	1	3	4
Mangifera indica	Mangga	Anacardiaceae	0	1	3	4
Mangifera quadrifida	Mangga	Anacardiaceae	1.5	1	4	4
Pentaspadon motleyi	Plaju	Anacardiaceae	0	1	2	4
Semecarpus cuneiformis	Rengas	Anacardiaceae	0	-1	2	4
Semecarpus forstenii	Rengas	Anacardiaceae	0	-1	2	4
Semecarpus nigroviridis	Rengas	Anacardiaceae	0	-1	2	4
Spondias pinnata	Kedondong hutan	Anacardiaceae	0	-1	2	6

Appendix 2: Sensitivity and adaptability traits

Sensitivity and Adaptability traits used to assess climate change vulnerability and **resilience**. Thresholds indicate the direction of vulnerability, upon which the score is based: these are the scores used to create the climate change vulnerability score for each species. Traits that were not used to calculate this score are indicated as 'Not Included'. Responses to questions as No, Yes or Unknown are indicated (of the 247 species). Rarity scores are explained in Appendix 3.

Sensitivity

Specialised habitat and/or microhabitat requirements

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
Temporary freshwater dependence	S1: Species is known to depend exclusively upon natural freshwater habitats that are temporary in nature	Low = false High = true	N= 0 U = 0 Y= 1	245	1	1
Habitat specialisation	S2: Species described (with justification) as having specialised habitat requirements	Low = false High = true	N= 0 U = 0 Y= 1	237	5	5
Microhabitat specialisation	S3: Species is dependent on one or more microhabitats	Low = false High = true	N= 0 U = 0 Y= 1	174	0	73
Seedbank dependence	S4: Species requires a long-term seedbank as part of its life-cycle	Low = false High = true	Not included	203	38	6
Saltwater intrusion	S5: Species occurs exclusively in habitats that are vulnerable to salt water intrusion	Low = false High = true	Not included	247	0	2

Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
Inundation intolerance	S6: Species is highly intolerant of inundation (can only tolerate <1 month) and is NOT a 'true aquatic'	Low = false High = true	N= 0 U = 0 Y= 1	109	7	131
Desiccation intolerance	S7: Species is highly intolerant of water absence (can only tolerate <1 month)	Low = false High = true	N= 0 U = 0 Y= 1	191	1	55
Desiccation tolerance	S8: Species is tolerant of water absence (can tolerate >3 month drought)	Low = false High = true	Y = -1 N = 0 U = 0	124	0	123
Intolerant of flood regime changes	S9: Does this species depend upon a specific flooding regime to maintain habitat?	Low = false High = true	N= 0 U = 0 Y= 1	229	1	19

Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
Vulnerable to increased flooding	S10: Vulnerable to increased flooding	Low = true High = false	N= 0 U = 0 Y= 1	152	15	80
Tolerant of increased flooding	S11: Can likely tolerate increased flooding	Low = true High = false	Y = -1 N and U = 0	0	6	241
Storm vulnerability	S12: Species intolerant of conditions associated with storms e.g strong wind impacts on soft wood species	Low = false High = true	N= 0, U = 0 Y= 1	202	7	38
Landslide vulnerability	S13: Species grows only on steep slopes vulnerable to mudslides	Low = false High = true	Not included	245	0	2
Waterlogging sensitivity	S14: Species grows only on flat areas with poorly drained soils, and does not have adventitious or rapidly produces roots	Low = false High = true	Not included	247	0	0
Intolerant of fire regime changes	S15: Species is described as being vulnerable to increased fire frequency	Low = false High = true	N= 0 U = 0 Y= 1	41	200	6
Tolerant of fire regime changes	S16: Species is vulnerable to decrease in fire frequency or fire tolerant	Low = true High = false	Y = -1 N and U = 0	238	9	0
Specific humidity requirements	S17: Sp has specific humidity requirements	Low = false High = true	Not included	247	0	0

Dependence on a specific environmental trigger that is likely to be disrupted by climate change

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
OA oscillation-related fluctuations	S18: Species is known to undergo population fluctuations as a result of Ocean-Atmosphere oscillations	Low = false High = true	Not included	222	0	25
Rain + drought to seed or germinate	S19: Species requires a period of wet weather followed by drought in order to produce seeds or germinate	Low = false High = true	N= 0 U = 0 Y= 1	178	7	62
Drought + rain to flower or germinate	S20: Species requires a period of drought followed by rain in order to flower or germinate	A specific flowering regime, but unclear how this links to CC vulnerability	Not included	182	3	62
Drop in water level to flower or germinate	S21: species requires a drop in water level in order to flower or germinate	Low = false High = true	Not included	217	0	30
Mast seeding	S22: Species exhibits mast seeding at intervals greater than one year	Low = false High = true	N= 0 U = 0 Y= 1	237	10	0
Temperature triggers	S23: Seed production, germination and/or flowering are triggered by a change in temperature	Low = false High = true	Not included	45	7	195

Interspecific interactions which could be disrupted by/emerge as a result of climate change

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
Decreasing positive interactions with other species	S24: species requires its habitat to be trampled by large animals in order to make it suitable for growth	Low = false High = true	Not included	247	0	0
	S25: Species is carnivorous and relies upon five or less prey species, or it is a specialist nematode feeder	Low = false High = true	Not included	247	0	0
	S26: Species is parasitic and rellies upon only one or a few other species in order to derive its nutrients	Low = false High = true	Not included	247	0	0
	S27: Species is epiphytic and rellies upon only one or a few host species	Low = false High = true	Not included	247	0	0
	S28: Species depends upon only one or a few other species for pollination	Low = false High = true	N= 0 U = 0 Y= 1	169	40	38
	S29: Species depends upon only one or a few other species for seed dispersal	Low = false High = true	N= 0 U = 0 Y= 1	235	1	11
	S30: Species has highly specialized mychorrizhal associations	Low = false High = true	N= 0 U = 0 Y= 1	41	9	197
Increasing negative interactions with other species	S31: Species could experience increases in one or more of the following as a result of climate change: Predation, competition, parasitism, disease	Low = false High = true	Not included	1	0	249

Low Adaptability

Poor Disperability

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
Extrinsic barriers to dispersal	A1: Extrinsic barriers to dispersal	High = occurs exclusively on mountaintops, or areas where dispersal is blocked by unsuitable habitat Low = No known barriers	Not used	247	0	0
Low intrinsic dispersal capacity	A2: Species disperses exclusively by barochory	Low = false High = true	Y = 1 U and N = 0	NA	8	NA
Low intrinsic dispersal capacity	A3: Estimated to only disperse by <1 km per year	Low = false High = true	N= 0 U = 0 Y= 1	195	27	25
High intrinsic dispersal capacity	A4: Estimated disperse by >1km per year	Low = false High = true		NA	169	NA

Poor evolvability

Trait Groups	Traits	Thresholds	Score	No	Yes	Unknown
Low rate of developing novel traits	A5: Species cannot reproduce sexually	Low = false High = true	Not used	247	0	0
Low rate of developing novel traits	A6: Species does not reproduce until the age of 10 years or older	Low = false High = true	N= 0 U = 0 Y= 1	174	19	54
High rate of developing novel traits	A7: Species can reproduce from 1 years old	Low = false High = true	Y = -1	174	19	54
Low rate of developing novel traits	A8: Species produces 10 or less seeds per year.	Low = false High = true	N= 0 U = 0 Y= 1	245	2	0
High fecundity	A9: Species produces 100 or more seeds per year.	Low = false High = true	Y = -1 U and N = 0	NA	177	NA
Pioneer	A10: Pioneer species	Low = false High = true	Y = -1 U and N = 0	185	60	2
Pest/Crop/Ornamental	A11: Established outside native range	Low = false High = true	Y = -1 U = 0 N = 1	113	40	94
Low genetic diversity	A12: Species is described as having a known lack of genetic diversity (e.g. A known historic bottleneck)	Low = false High = true	Not used	5	0	242
Borneo endemic	Species occurs exclusively in Borneo. For further explanation see Appendix 3.		Y = 1 U or N = 0			

Appendix 3: Range

To obtain data on focal species' distribution ranges, the UK's Royal Botanical Gardens, Kew, collated broad-scale distribution data for c. 70% of species listed in Appendix 1. This was carried out using data sourced from the Global Biodiversity Information Facility (https://www.gbif.org/) and Kew's own specimen collections. For the most widespread species, these formed the basis of the maps below. For the more narrowly distributed species, a synthesis of roughly 'province level' data was compiled from regional flora treatments (e.g. The Tree Flora of Sabah and Sarawak (Soepadmo et al. 2004)). The extent of a species' range can also be used as a metric of sensitivity (species with small ranges are more likely to be vulnerable to a specific set of climate change effects e.g. warming temperatures plus increasing rain, while species with large ranges may experience mixed climate changes), but was kept separate as it is not a biological trait.

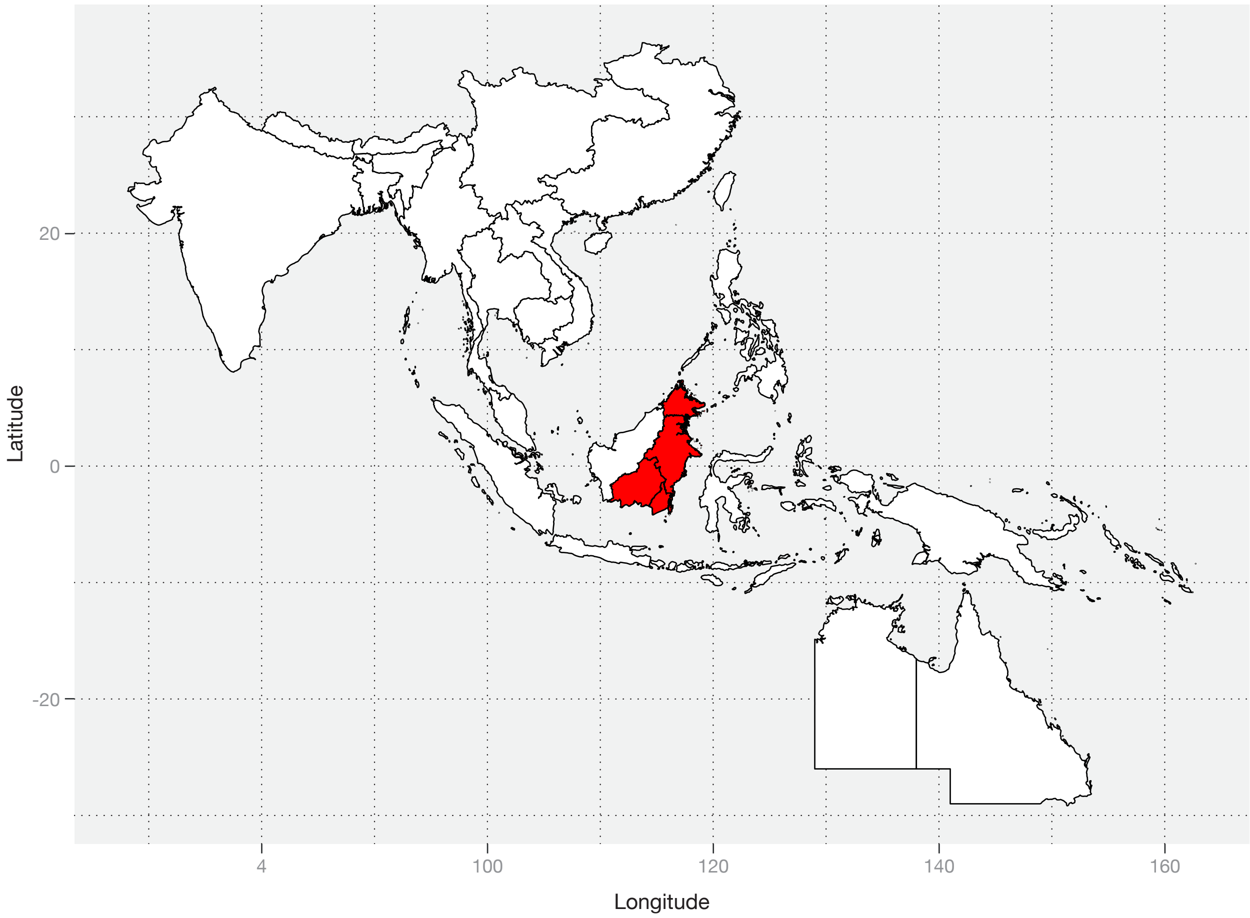


Figure A3.1 An example of a species scored 1 for range: the species has a small range and the population is vulnerable to climate change. Geographic area considered = white filled land surface, while red = presence of *Macaranga pearsonii* at the province level in Borneo.

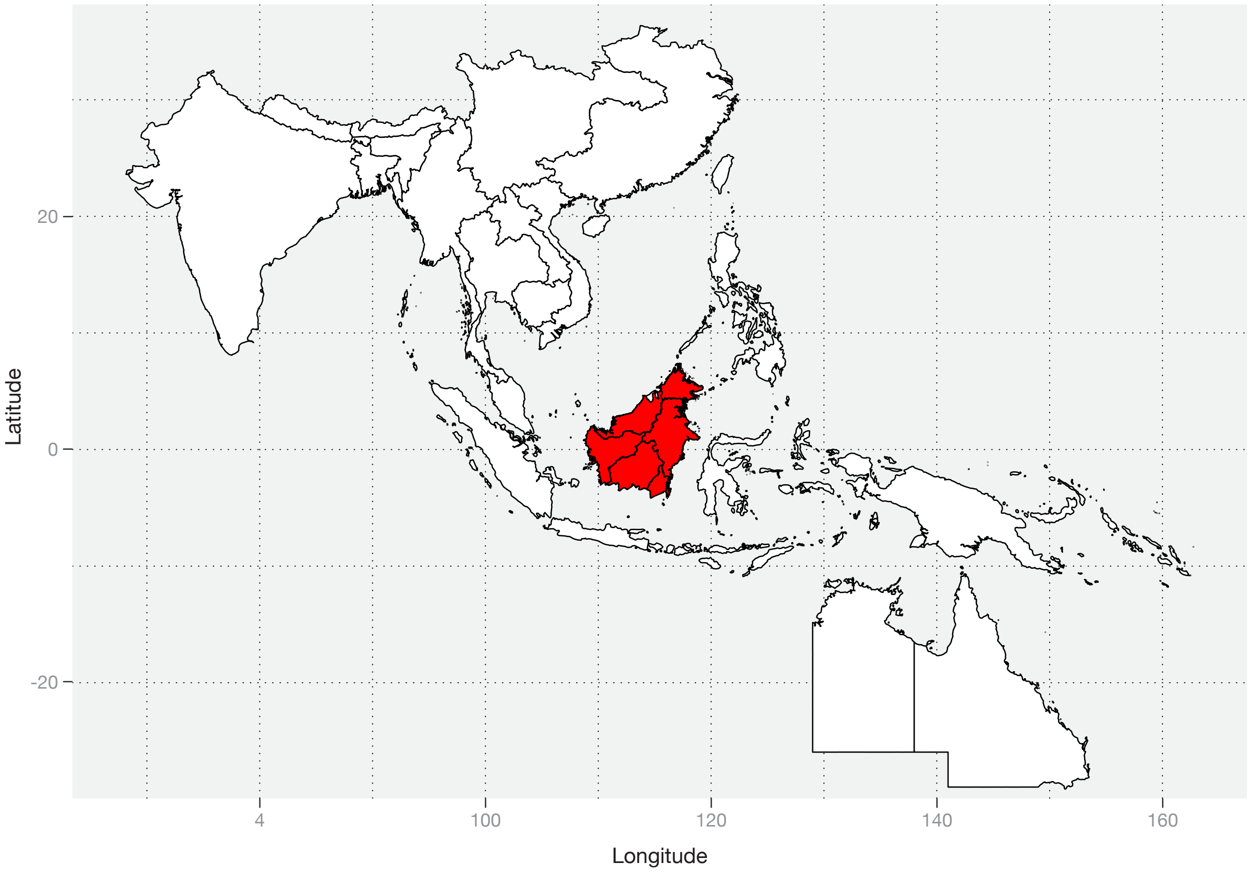


Figure A3.2 An example of a species (*Alseodaphne elmeri*) scored 1 for range.

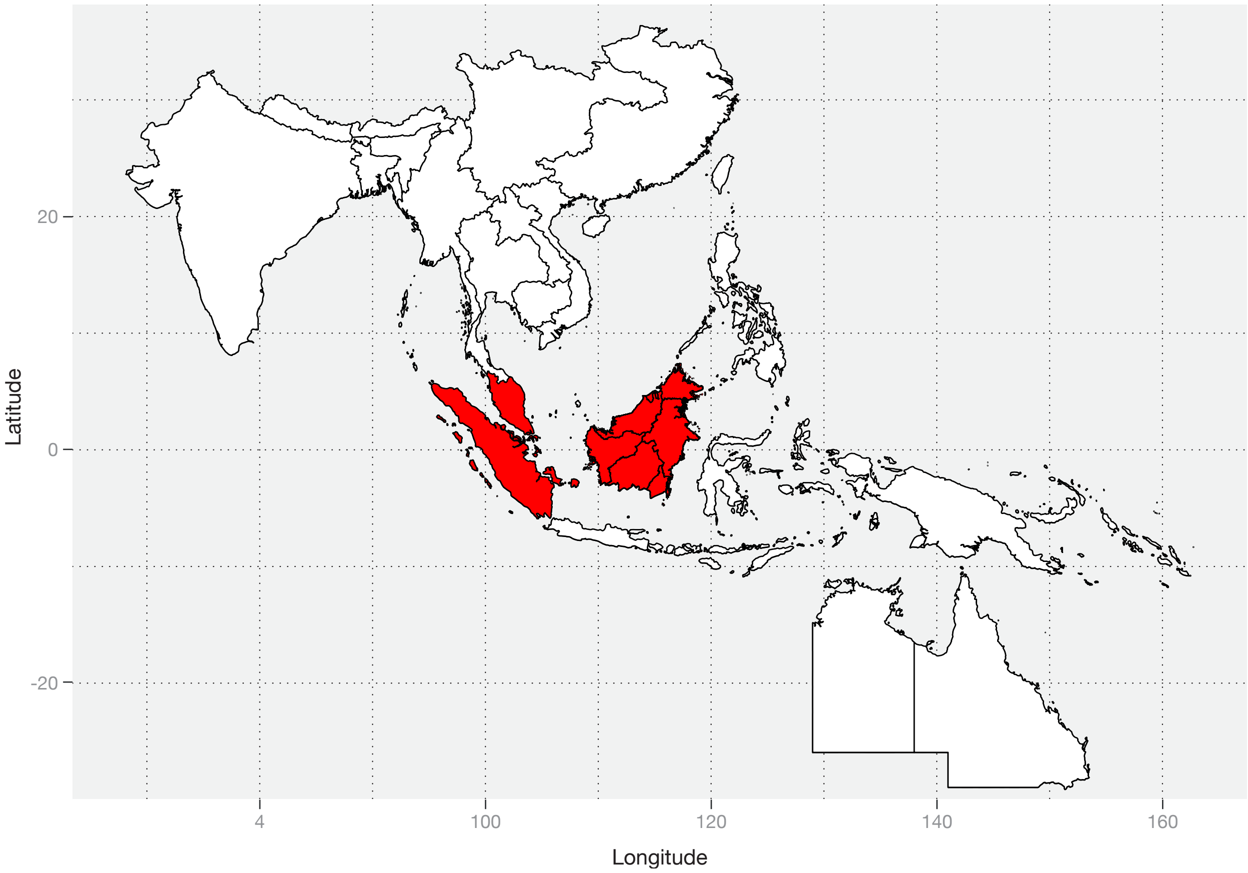


Figure A3.3 An example of a species (*Anisophillea disticha*) scored 0 for range.

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