THREATS TO WILD ORANGUTANS: A CASE STUDY IN KUTAI NATIONAL PARK OF EAST KALIMANTAN, INDONESIA

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ABSTRACT

The Northeast Bornean orangutan (*Pongo pygmaeus morio*) currently remains the only orangutan subspecies for which extinction risks cannot be accurately assessed due to a severe lack of information around the habitat conditions and threats that its different population units experience. Despite decades of acknowledgement as a stronghold for the *morio* subspecies, the orangutan metapopulation in Kutai National Park (KNP) of East Kalimantan, Indonesia is one unit that remains to be adequately studied. This report presents a preliminary analysis of the threats to the orangutan subpopulation in the northeastern region of KNP using habitat assessments and observational notes of the human activities in and around this area. Current threats identified include industrial mining, agricultural activities and clear-cutting around this protected area, while illegal logging, fire sources and severe climate events threaten the interior forests. Poaching in relation to human-orangutan conflicts and negligent tourism practices were also identified as threats to the greater metapopulation in KNP. The results of this study can contribute to the foundation of information required to adequately assess and develop appropriate conservation efforts for the orangutan population unit of KNP.

Keywords: orangutan, *Pongo pygmaeus morio*, extinction threat, habitat assessment

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FOREWARD

My seemingly inborn passion for orangutans, a close evolutionary relative and profoundly fascinating animal, directed the conception and realization of this research, while the imminent threat of their extinction fueled its completion. At the start of my studies, I set out to build upon my understanding of the various factors that contribute to the conservation crisis of orangutans. Specifically, I was interested in learning about the efficacy of different conservation initiatives with orangutans, and the degree to which adverse human activities, environmental activism and climate breakdown via global warming contribute to this crisis. With these objectives in mind, I decided to conduct a preliminary analysis of the threats to orangutans in an area of Kutai National Park where a similar research question had not been addressed in over two decades. This study has required me to explore this issue with little relevant research to reference, which has forced me to personally contemplate and diligently examine all aspects of orangutan life in this forest. By virtue of the complexity of this conservation issue, I was able to accomplish most of my learning objectives with this research alone; the remaining objectives were satisfied through environment-based courses and conferences.

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To my always, Alexandre, and my furry companions

INTRODUCTION

The few non-human great ape species that remain throughout equatorial Africa and Southeast Asia experience similar threats to their long-term viability, including adverse human activities (e.g., poaching and land-use changes; Hickey et al. 2013; Strindberg et al. 2018; Voigt et al. 2018) and ecological challenges associated with regional climate change (Lehmann et al. 2010; Masi et al. 2012; Sesink Clee et al. 2015; Ssentongo et al. 2018; Struebig et al. 2015). Among the most endangered are the three species of orangutans that survive across Borneo (*Pongo pygmaeus*) and Sumatra (*P. abelii*, *P. tapanuliensis*). Over the last four decades, wild orangutan populations have experienced extensive habitat loss via droughts, wildfires and conversion to other land-uses (Gaveau et al. 2014; Miettininen et al. 2016) as well as unsustainable poaching rates, for which a number of motivators have been identified (e.g., crop-raiding, capture for trade) (Wich et al. 2016; Abram et al. 2015). As a result, all three orangutan species are now considered Critically Endangered (Ancrenaz et al. 2016a; Nowak et al. 2017; Singleton et al. 2017) and few populations are projected to be viable within the next 100 years under a business-as-usual scenario (Utami-Atmoko et al. 2017).

In order for conservationists to devise effective efforts at conserving viable orangutan populations, there must be a strong foundation of data from both quantitative analyses of the given population (e.g., up-to-date nest censuses) and qualitative reports of the habitat conditions and threats present within the region. Statistical models can use this information to project the viability of a metapopulation (greater population of 2+ interconnected subunits) under its current conditions, which is necessary to identify units at risk of extinction (e.g., Utami-Atmoko et al. 2017; Santika et al. 2017). Currently, the Northeastern Bornean orangutan (*Pongo pygmaeus morio*) remains the only *Pongo* taxon for which population viability cannot be assessed due to a severe lack of information for each MP (Utami-Atmoko et al. 2017). One *P.p. morio* subpopulation for which the habitat conditions, population dynamics and threats over the past two decades have not been systematically assessed is in Kutai National Park (KNP) of East Kalimantan, Indonesia. This is despite the likelihood that KNP, if protected, may be one of the last strongholds for *P.p. morio* (Wich et al. 2008; Utami-Atmoko et al. 2017).

The present study aims to document and characterize the human and climatic activities that degrade orangutan-inhabited forests in the NE region of KNP. As background, I first synthesized key information on the habitat requirements of Bornean orangutans and the various factors that lower the quality of their habitats. I then present my assessment and analysis of the current threats to orangutans (*P.p. morio*) living in close proximity to human populations and activities in the NE region of KNP. Assessments involved recording evidence of logging and other forms of habitat disturbance (e.g., drought, fire, agricultural clearings) around two research sites within KNP and noting the human activities and state of forests in the adjacent unprotected areas.

LITERATURE REVIEW

1. Orangutan Habitat Requirements & Restrictions

Habitat that is considered 'suitable' or of 'good quality' for Bornean orangutans (*P. pygmaeus* sp.) is determined by an area's climate (as it relates to the productivity and temporal availability of fruits), land-cover, and level of threat from human activities (Wich et al. 2015). In general, forests able to support high densities of orangutans provide higher quality habitats for their populations (Marshall et al. 2009a).

A habitat's carrying capacity for Bornean orangutans is mainly determined by its production of orangutan plant foods, and limited by the availability of fruit and non-fruit foods during periods of low fruit productivity. In other words, habitats that produce a stable level of fruits throughout the year yield greater food security and higher carrying capacities than those that undergo cyclical fluctuations in fruit availability, such as in masting habitats (Delgado & van Schaik 2000; Marshall et al. 2009a; Wich et al. 2011). In masting forests, such as those dominated by dipterocarp tree species, orangutans cope with low fruit periods (LFP) by shifting to feeding on higher proportions of bark, leaves, flowers and non-masting fruits (e.g., figs), all of which have a relatively low caloric content (Harrison & Marshall 2011; Knott 1998; Leighton 1993). When and where only very low-quality food items are available during periods of fruit scarcity, orangutans can suffer nutritional deficits that result in fewer births and higher rates of starvation (Knott 1998, 2001).

The 'best quality' habitats for *P. pygmaeus* sp. are found in forests that offer a mosaic of multiple habitat types within a single orangutan's home range (Husson et al. 2009). By providing access to several habitat types - each of a different floristic composition, phenology and productivity - habitat mosaics allow orangutans to overcome LFP in more ‘seasonal’ patches by moving to patches with foods that are less preferred and/or available year-round, also known as fallback foods (FBF, e.g., figs, liana products, cambium, leaves) (Harrison & Marshall 2011; Husson et al. 2009). Orangutans densities are typically highest in mosaics that contain freshwater fringes (e.g., alluvial/swamp forests) and patches of lowland forest that contain a stable supply of fruits (Delgado & van Schaik 2000; Rijksen & Meijaard 1999).

In Borneo, these high-quality habitats are generally found within the Intermediate Rainfall Zone (IRZ), where forests receive *ca*. 150-250 mm rainfall/mo in the dry season and *ca*. 200-400 mm/mo in the wet season (Santika et al. 2017). The dry and alluvial lowland forests in this zone receive enough annual rainfall (>2,400 mm) for important orangutan foods to grow (e.g., *Moraceae* [e.g., figs] and *Anacardiaceae* [e.g., mangoes]), but not too much rainfall (<3,600 mm) to stunt forest productivity with greater cloud cover and soil leeching (Santika et al. 2017; Wich et al. 2012). Peatland forests in this zone also provide high-quality habitats for *P. pygmaeus* sp. because, unlike masting or seasonal (dryland) forests where fruits are diverse but only temporarily abundant, fruit productivity in peatlands is relatively aseasonal which affords orangutans a stable (albeit low) supply of fruits year-round (Cannon et al. 2007; Husson et al. 2009; Lanjouw et al. 2015).

Some selectively logged forests throughout Borneo have also been found to support large orangutan populations (Husson et al. 2009; Morrogh-Bernard et al. 2013), occasionally at densities higher than those found in comparable primary [unlogged] dipterocarp forests (Ancrenaz et al. 2010; Payne & Prudente 2008). Even industrial forest concessions that employ sustainable forestry practices such as reduced impact logging (RIL) can maintain relatively high orangutan carrying capacities if they ensure sufficient regrowth periods between logging events, minimize further damage (e.g., from tree falls) and preserve important tree species in the orangutan’s diet (see Lagan et al. 2007 for RIL in Dermakarot Forest Reserve, Sabah) (Utami-Atmoko et al. 2017).

Orangutans’ large body size and arboreal lifestyle have predisposed them to excel in forest conditions that allow the use of energy efficient locomotion while foraging and travelling (Felton et al. 2003; Rao & van Schaik 1997). Although a contiguous tree canopy is not necessarily required for a habitat to be suitable for orangutans (as shown by the densities that selectively logged forests can support; Husson et al. 2009; Ancrenaz et al. 2010), it does improve their ability to move laterally through the canopy, which is more energy efficient than ascending and descending trees to cross large canopy gaps (Ancrenaz et al. 2014; Cant 1987; Davies et al. 2017; Felton et al. 2003; Rao & van Schaik 1997). A tall, closed tree canopy also allows orangutans to nest, forage and travel at a greater distance from ground predators (primarily humans), provides shelter from the elements (e.g., heavy rain, strong wind) and can minimize the risk of injury associated with using weakened or damaged branches near canopy gaps (Ancrenaz et al. 2014; Davies et al. 2017; Thorpe et al. 2007).

Temperature – perhaps as it relates to fruit availability and/or thermoregulatory constraints – is also considered a determinant of habitat suitability for orangutans (Gregory et al. 2012; Struebig et al. 2015; Wich et al. 2012, 2015). For one, both orangutan densities and temperatures decline appreciably with altitude throughout Borneo (Husson et al. 2009). Important orangutan foods (fleshy-pulp fruits, figs and liana species) have also been reported absent from colder, higher altitude forests (> 500 m above sea level [asl]), yet plentiful in the warmer lowlands (e.g., Gunung Palung National Park, West Kalimantan; Marshall 2004, 2009b). The colder climates found at higher altitudes may be unsuitable for growing important orangutan foods (Husson et al. 2009), which could explain why Bornean orangutans are found at very low densities (if at all) in high altitude forests. Other types of land cover in Borneo that cannot alone support an orangutan population due to their lack of nutritious, edible fruits include plantation monocultures, mangroves, heavily logged forests and heath forests (Husson et al. 2009; Marshall et al. 2007). Of these, oil palm plantations provide the lowest-quality habitats to orangutans, particularly where devoid of patches of natural forest (Ancrenaz et al. 2015; Wich et al. 2012).

Because orangutans can be reluctant to traverse vast open areas and may only do so when ecologically stressed (Delgado & van Schaik 2000), a subpopulation can become isolated from its source population when forested areas linking orangutan habitats are replaced by expanses of non-forest land (Rijksen & Meijaard 1999; Ancrenaz et al. 2010). In order to maintain viable orangutan populations, i.e., populations with good demographics and healthy genetic variability, >500 km^2 (ideally >1,000 km^2) of good quality habitat is estimated to be required in Borneo (Marshall et al. 2009c). In reality, very few populations throughout Borneo persist within protected forests that meet or exceed these criteria (Utami-Atmoko et al. 2017). Orangutan populations therefore require some form of connectivity between patches of good-quality habitat to allow individuals and genes to disperse throughout the metapopulation.

2. Threats to Habitat Quality

Major factors that have reduced the quality and suitability of habitats for Bornean orangutans over the past five decades are sketched below.

2.1. Habitat Degradation

The overwhelming majority of habitat degradation in Borneo has been caused by humans and has involved both small-scale activities, such as illegal logging, and large-scale [industrial] activities, such as the clear-cutting and conversion of forests to more profitable land-uses. In most areas throughout Borneo the impact of human activities has been exacerbated by worsening ENSO (El Niño Southern Oscillation) events that perturb climate conditions worldwide every 2.5-7 years with extreme temperature and precipitation swings (Cai et al. 2014). Together, human activities have worked in synergy with harsh climate conditions to degrade the quality of habitats across the Bornean species' range via extreme changes to land-cover and fruit availability (Struebig et al. 2015; Wich et al. 2015).

2.1.1. Logging. Logging activities have contributed significantly to the degradation and loss of orangutan habitats in Borneo over the past five decades (Ancrenaz et al. 2016a; Gaveau et al. 2014). Along with the locomotor challenges imposed by excessive canopy gaps (mentioned above), logging selectively targets large hardwood trees (e.g., dipterocarps, *Eusideroxylon zwageri*) which large strangling figs – an important orangutan FBF species – preferentially select as hosts on account of their strong structural support (Lambert 1991; Leighton & Leighton 1983). The large crop size produced by strangling figs allows orangutans to concentrate their foraging efforts in one area and minimize travel costs (Leighton et al. 1993), so their near absence from selectively logged forests can force orangutans to employ more energetically costly foraging behaviours as they search for less concentrated food sources (Felton et al. 2003). In addition to other adverse effects, this can leave less energy available for reproduction and immunodefence against parasites and diseases (van Schaik et al. 2001). Logging can also cause direct fatalities when trees are felled with orangutans in them (Davies 1986; Rijksen & Meijaard 1999; Yoshiba 1964) and afford greater access to hunters and poachers in areas that had been previously inaccessible (Husson et al. 2009).

The immediate effect of logging in orangutan inhabited forests depends on several factors, including the dietary flexibility of the taxon impacted, the intensity and type of logging and the presence of post-logging hunting activities (Husson et al. 2009). Relative to its more western conspecifics in Borneo, the Northeastern Bornean subspecies (*P.p. morio*) persists within the driest and least productive habitats on Borneo (Taylor & van Schaik 2007) and has a number of physiological and behavioural traits that enable individuals to withstand periods of extreme fruit scarcity. In particular, *morio* are better suited to harvest difficult-to-digest resources (such as high-fibre leaves and bark) by virtue of their (i) more robust mandibles and maxillary modifications that enhance mastication of resistant foods (Taylor 2009) and (ii) higher proportion of daily time spent resting, which may improve fibre digestion (Morrogh-Bernard et al. 2009). *Morio* also show genomic enrichments associated with improvements to cardiovascular activity, lipid metabolism and energy storage, all of which improve their ability to survive in a resource restricted environment (Mattle-Greminger et al. 2018). These adaptations may explain how *morio* is able to persist on a diet overwhelmingly composed of fibrous foods (occasionally >80% leaves and bark) during LFP (Kanamori et al. 2010; Russon et al. 2015).

As a result, *morio* is considered extremely resilient to disturbances that lower the quality and/or quantity of foods in their habitats, based on studies that found either no influence of logging on *morio* densities (Marshall et al. 2006, 2007) or complete recolonization of logged forests after a 10-15 year period (Ancrenaz et al. 2010; Lackman-Ancrenaz et al. 2001). In comparison, both western subspecies (*P.p. wurmbii* & *P.p. pygmaeus*) are subject to less pronounced droughts and periods of fruit scarcity (see Qian et al. 2013) and their populations live mostly within lowland swamp mosaics which offer highly suitable ecological conditions (Kanamori et al. 2016). This has led researchers to believe they are less adapted [and thus less resilient] to logging within their habitats (Husson et al. 2009), but the impact of logging on both subspecies remains greatly understudied (see Hardus et al. 2012). The response of each subspecies to logging can also be difficult to compare because each site has its own logging history, intensity, and conditions prior to logging (Marshall et al. 2006).

In general, available evidence suggests that Bornean orangutans cope well with low intensity logging (<5 trees/ha, e.g., RIL) with little to no change in density, but poorly with higher intensity logging (>5 trees/ha) where uncontrolled and illegal practices can cause high rates of incidental damage to non-felled tree and liana species (Johns 1988) that provide important food for orangutans (Alfred et al. 2010; Husson et al. 2009). At the onset of logging within their habitats, orangutans typically move into less disturbed patches of adjacent forests, which can result in an overcrowding of refugial habitats if they are already occupied at carrying capacity (Ancrenaz et al. 2004, 2005, 2010; Davies 1986; MacKinnon 1971, 1974; Marshall et al. 2006; Morrogh-Bernard et al. 2003). It is then likely that intense competition for limited resources would result in the competitive exclusion of some individuals, who would then disperse into other suboptimal habitats (if available) or die from starvation (van Schaik 2004).

In some cases, orangutans may remain in degraded forests following logging events if their habitat is isolated from other forest patches or if they become competitively excluded from neighbouring refuges (Meijaard et al. 2005). Female orangutans in the disturbed forests of Tuanan (*P.p. wurmbii* in Central Kalimantan) have been found to remain within their home range even after part of it had been deforested (Singleton et al. 2009). Residents that remain in degraded forests can either search for high-quality foods over a larger range (expending more energy doing so) or adopt a ‘sit and wait’ foraging strategy and temporarily consume low-quality forage (Morrogh-Bernard et al. 2009).

Whether or not orangutans can recolonize logged forests depends on many factors, including the target species for logging, intensity of logging, number of times the forest has been logged, length of time between logging events, and how tree species composition recovers post-logging (Ancrenaz et al. 2010). From the perspective of an orangutan, a single logging event that removes <5 trees/ha, avoids felling fruit trees, minimizes incidental damage and leaves logged areas to regenerate for a sufficient period (as per RIL practices) may minimally impact the suitability of their habitats (Ancrenaz et al. 2010; OCSP 2010). The type of logging employed can also determine how an orangutan population is impacted. Illegal [small-scale] logging, for example, can target substantially more tree species that provide food to orangutans than legal logging (Husson et al. 2009) but is known to cause less collateral damage to non-felled trees and lianas than mechanized logging (Husson et al. 2009; Rao & van Schaik 1997). Especially at sites where mechanized practices carve logging roads out of closed forests, logging can also trigger an influx of hunters/poachers and other disturbances in the area (e.g., settlements, development projects) (Leighton et al. 1993; Ancrenaz et al. 2004).

In some cases, low-intensity logging practices can improve the supply of foods to orangutans in affected forests. When canopy gaps are created from low-intensity logging, the species that compete to fill out the canopy can provide nutritious, edible plant parts and safe nesting sites for orangutans to use (e.g., *Neolamarckia cadamba*, *Dracontomelon sp.*, *Ficus sp.*) (Ancrenaz et al. 2010; Meijaard et al. 2005; Payne & Davies 2013). In addition, many of the old-growth hardwood trees targeted for timber fruit infrequently and/or offer few edible resources to orangutans (e.g., Dipterocarps, *Eusideroxylon zwageri*), whereas some pioneers that replace them mature rapidly and can fruit several times a year once mature (Ancrenaz et al. 2010; Meijaard et al. 2005). Certain mature climax trees that remain in logged forests (e.g., *Litsea sp.* and *Garcinia sp.*) have been found to grow more new leaves (Johns 1988) and fruit more regularly outside synchronized fruiting patterns after logging events (Marshall et al. 2009a). Given a sufficient recovery period for the canopy to close and for successional species to mature, lightly-logged 'mixed-dipterocarp' forests may offer a greater supply of fruits and young leaves than comparable unlogged forests (Chivers 1972, 1974; Wilson & Wilson 1975; Whitmore 1975) that orangutans can use to weather LFP. This may explain the ability of such forests to support high population densities when left to regenerate for 10-15 years (Ancrenaz et al. 2010).

2.1.2. Climate. One major influence of climate [and habitat] conditions across the range of *P. pygmaeus* sp. is the interannual variation of wind conditions over - and sea surface temperatures in - the Pacific Ocean, described by the ENSO cycle (Supari et al. 2018). The warming phase of this cycle, El Niño, lowers rainfall over Southeast Asia which prolongs drought conditions in Borneo, while the cooling phase, La Niña, induces heavy rainfall over this region. As greenhouse gas emissions continue to accelerate around the world, tropical forests are expected to experience a higher occurrence of extreme El Niño droughts (Cai et al. 2014; Thirumalai et al. 2017) and more pronounced swings in average interannual rainfall (Bonfils et al. 2015; Power & Delage 2018).

At a smaller scale, excessive canopy disruptions from logging activities can perturb local climate conditions in logged forests because they change shade/light conditions under the canopy and the moisture availability, evapotranspiration and surface albedo (proportion of incident sunlight reflected by land-cover) of the environment, leading to higher air surface temperatures and lower levels of precipitation (Hardwick et al. 2015; McAlpine et al. 2018). Extreme El Niño drought conditions and logging activities will likely act in synergy upon orangutan habitats to make forests more vulnerable to burning from fires (Becek & Horwath 2017) and alter precipitation patterns such that only drought, fire and flood-resistant species bear fruit and/or survive (Santika et al. 2017; Struebig et al. 2015). If important orangutan FBF are unable to grow and survive in these altered climate conditions, fewer orangutans may survive within affected forests when fruit becomes scarce, making those habitats less suitable for them.

The two changes to regional climate that may be most problematic for Bornean orangutans include shifts to temperature ranges (annual and diurnal) and rainfall during the driest months of the year (Wich et al. 2015). This is because in addition to the physiological (e.g., thermoregulation) and behavioural challenges (e.g., greater resting demands) that orangutans face with such climatological changes (Carne et al. 2015), their forested habitats are expected to become less resistant to wildfires and hold fewer quality food items (Wich et al. 2015). By 2080, 63% of habitat area that was suitable for Bornean orangutans in 2010 are expected to lose suitability from regional climate change alone (Struebig et al. 2015); this includes forests that are currently considered regional strongholds, such as KNP.

Even if the availability of important orangutan foods is not significantly threatened by future climate change (e.g., Lee et al. 2019), the permanence of their forested habitats may be. Over the last fifty years, extreme El Niño conditions have caused anomalously high number of tree deaths from drought stress (Leighton & Wirawan 1986; Lingenfelder & Newbery 2009; Slik 2004; van Nieuwstadt & Sheil 2005) and enabled fires to spread into dryland forests, mostly from agricultural lands but also from deliberate arson (Gaveau et al. 2016; Dennis 1999; Dennis et al. 2005), particularly throughout eastern and southern Borneo where rainfall is lowest (Miettinen et al. 2017; Qian et al. 2013). Damage caused by droughts and fires has been most intense in logged- and previously burned-forests where excessive amounts of tinder on the forest floor – including standing deadwood, timber debris, leaf litter, dry root mats and desiccated climbers - can provide ample fuel to fires that enter the forest (Lennertz & Panzer 1984; Uhl & Kauffman 1990). Since the greatest number of wild Bornean orangutans currently remain in selectively logged forests (Voigt et al. 2018), future droughts and fires represent a major threat to these orangutans and their remaining habitats.

Separately, severe droughts predominantly harm the large-stature trees of forest canopies that are more prone to hydraulic failure (vessel cavitation) when water stressed (Hacke et al. 2001; Slik et al. 2013) and fires disproportionately injure small trees (<10 cm dbh) whose inner cambial tissue is less protected from burning compared to larger trees with thicker bark (Barlow et al. 2003; Leighton & Wirawan 1986; van Nieuwstadt & Sheil 2005). The destructive combination of these disturbances can substantially diminish two tree classes that are important to forest regeneration – larger trees that supply seeds and smaller trees that ensure vegetation for succession (van Nieuwstadt & Sheil 2005). The ability of droughts and fires to cripple, or at least handicap, forest regeneration can make them more deleterious to orangutan habitats than logging activities.

On the forest floor, fires disproportionately impact late successional tree species by eliminating their large [fire-sensitive] seeds (Slik & Eichhorn 2003; van Nieuwstadt & Sheil 2005), which limits their regenerative ability to sproutings from basal plant parts and seed deposition from mature unburned trees (Goldammer et al. 1996; van Nieuwstadt 2002). Although once-burned forests are able to regenerate when left undisturbed for 10-20 years (Slik et al. 2002), this ability can be diminished when recurring fires destroy the highly-sensitive resprouts from late-successional species and remove pioneer regrowth without the chance to replenish the seed bank from which they sprouted (Slik & Eichhorn 2003; van Nieuwstadt 2002). Repeated fires over a short period of time can eliminate climax and pioneer species from the regenerative pool and allow non-forest wind-dispersing invaders (e.g., ferns, bamboo and *Imperata* grasses) to colonize and rapidly dominate burnt lands (Kartawinata 1993; Kartawinata & Vayda 1983; Mori et al. 2000). Regeneration within burned forests can also be stunted when, in the case of intense fires, the upper soil layer is sterilized of available nutrients and mycorrhizal communities upon which important climax tree species (e.g., Dipterocarps) depend for growth and survival (Certini 2005), or when logging activities harvest fire-tolerant hardwoods (e.g., Bornean ironwood, *Eusideroxylon zwageri*; Tagawa et al. 1988; Goldammer & Siebert 1990) that can otherwise provide shade to speed up succession and thwart light-demanding invaders.

Part of the reason why droughts and fires are detrimental to orangutans is the near-elimination of high-quality FBFs from affected habitats. For example, important aseasonal orangutan fruits from large woody climbers (e.g., *Annonaceae*) and figs (*Ficus* subg. *Urostigma* & subg. *Ficus* sect. Rhizocladus) experienced 97% and 90% mortality (respectively) following the severe 1982/83 El Niño drought and fire in the near-primary KNP forest (Leighton & Wirawan 1986). An additional 25% of all canopy trees died from drought stress following the fires at this site, reducing the potential for host-dependent FBFs (e.g., hemiepiphytic *Urostigma*) to regenerate in the burned forest (Leighton & Wirawan 1986). A severe shortage of high-quality FBFs can persist for several years following an extreme drought and fire event (until the regrowth begins to fruit), which can put surviving orangutans at a high risk of starvation, particularly for those in isolated forest patches. In forests that experience cooler surface fires, certain terrestrial herbaceous vegetation (e.g., gingers) can regrow rapidly following a fire event if their reproductive parts escape burning; this regrowth helped orangutans in the 1983 burnt KNP forests stave off starvation (Leighton & Wirawan 1986; Suzuki 1988). Many orangutans may incur fatal injuries before this point, however, either directly from the fire or indirectly from respiratory complications and debilitating injuries (Ancrenaz et al. 2016a; Erb et al. 2018; Rijksen & Meijaard 1999; Utami-Atmoko et al. 2017).

2.2. Habitat fragmentation

Habitats can also become less suitable for wild Bornean orangutans when non-forest lands fragment contiguous forest blocks into several smaller patches, causing travel between habitat fragments to be obstructed or dangerous for travellers.

2.2.1. Agriculture. One of the most common causes of habitat fragmentation in Borneo is the clear-cutting of forests for large-scale/industrial monoculture plantations (most importantly, oil palm) (Ancrenaz et al. 2010). Alone, the young shoots and mature fruits of the oil palm tree cannot satisfy orangutans' nutritional or caloric requirements (Ancrenaz et al. 2015); this can sometimes result in orangutans starving to death if they venture too far into large plantations and cannot be rescued and relocated (Spehar et al. 2015).

Industrial plantations have been able to connect habitat fragments when patches of natural forest are preserved or incorporated into the landscape with the travel and dietary requirements of orangutans in mind (see Ancrenaz et al. 2015; Spehar & Rayadin 2017). However, industrial plantations across the orangutan's range are not required by law to retain any natural forest - other than riparian buffer zones - as ecological set-asides (Jonas et al. 2017). In fact, concessionaires in Kalimantan (Indonesian Borneo) can be discouraged from doing so due to 'productive [land-]use requirements' that allow the government to seize uncultivated lands and licence them out [again] for conversion (Cotula et al. 2015; Meijaard et al. 2017). Reconnecting habitats and preserving gene flow across fragmented landscapes must therefore involve changes to land-use planning and management systems to require the conservation of strategically-placed forest corridors within all new and unplanted concessions.

Given the financial and regulatory requirements behind licensing and managing a concession in Indonesia, many corporations that own palm oil plantations and processing mills have chosen to maximize their yield by purchasing crops from local independent smallholders (termed 'outgrowers') who operate largely without permits or enforced regulations (Naylor et al. 2019). This has led to the proliferation of smallholder agriculture in Kalimantan over the last few decades (Sheil et al. 2009; Rist et al. 2010) that has to some degree replaced or encroached upon orangutan habitats (Jonas et al. 2017) and intensified the interface between orangutan and human livelihoods. When agricultural fields encroach upon their habitats, orangutans show a degree of ecological flexibility by incorporating the anthropogenic landscape into their home ranges (Ancrenaz et al. 2015). Their propensity to "crop-raid" in such lands, however, has been linked to the availability of wild food in the forested portion of their home range (Ancrenaz et al. 2016b).

In Indonesia, smallholder farmers typically plant high-energy fruits such as jengkol (*Archidendron pauciflorum*) and durian (*Durio* spp.) along the edge of their fields for commercial profit and household consumption (Marchal & Hill 2009), which can attract nearby orangutans - especially during periods food scarcity (Ancrenaz et al. 2016; Campbell-Smith et al. 2011). Orangutans also forage on the flowers, seeds, sprouts and inner cambium of certain trees in plantations, and can cause significant damage to croplands in the process, especially to fields in early-stage growth (Marchal & Hill 2009; Ancrenaz et al. 2015). This creates a perception of orangutans as destructive pests (Hockings & Humle 2009) and sparks conflict between farmers and orangutans that can lead to the hunting or poaching of orangutans that crop-raid (Meijaard et al. 2011).

2.2.2. Mining, oil and gas. Mining concessions - which as of 6-7 years ago overlapped ca. 15% of *P. pygmaeus* sp. distribution – also continue to fragment suitable habitats throughout Borneo to exploit the vast deposits of coal, metals (e.g., gold, bauxite, lead) and minerals (e.g., zircon, other gemstones) found throughout Borneo (Lanjouw 2013; Meijaard & Wich 2014). Particularly around the KNP area and throughout East Kalimantan where large deposits of high-quality coal occur (Friederich & van Leeuwen 2017), open-pit mining operations devastate large expanses of forest by denuding the land of its vegetative cover, fertile soils and bedrock, and causing major pedological and hydrological changes to the mined area (Bell & Donnelley 2006).

Small-scale mining operations also employ potentially hundreds of thousands of workers in Kalimantan alone (Peluso 2018), including legal permit holders and non-registered (illegal) parties that are left largely unregulated and degrade forested areas with impunity (Siswanto et al. 2012). These activities can be more environmentally destructive than those of industrial mining – and even industrial agriculture – due to the sheer number of permit holders (e.g., 1,304 active licenses, mostly smallholder, covered 15% of East Kalimantan in 2012) and the lack consequences for non-compliant practices (Peluso 2018; Wich & Meijaard 2014).

By law, all mining concessions are required to develop and carry out five-year reclamation plans that specify how forest will be restored to a pre-mining state after operations cease, though most of these concessions (with few exceptions, including those around KNP) are left as wastelands with no potential to regain forest cover (Agus et al. 2016; Meijaard & Wich 2014; Jensen 2016). The highly profitable nature of mining in this region has also made land-use designations impermanent, as shown from the redrawing of the boundaries of KNP following the discovery of vast coal deposits inside the Park (McMahon et al. 2000). These excised lands have now been almost entirely deforested and converted to open-pit and strip mining.

For oil and gas industries in Borneo, the majority of operations (exploration and drilling) occur offshore and away from orangutan habitats (Meijaard & Wich 2014). However, these industries – along with industrial mining, forestry and agriculture across Borneo – often requires substantial land-based improvements to local infrastructure to support operations (i.e., new access and haul roads, bridges, power plants, worker settlements, conveyor belts) which frequently cut through forested habitats and disrupt landscape connectivity (Alamgir et al. 2019; Wunder 2003). Here too, the access these developments provide can also usher in human activities (illicit poaching, mining, logging) that may have been rare or absent prior to construction, placing added pressures on resident or nearby orangutan populations (Abram et al. 2015; MacKinnon 1986; Meijaard & Wich 2014).

2.3. Poaching

Some research suggests that intense hunting drove all orangutan populations beyond the Sunda Shelf to extinction and may have contributed to the absence of orangutans from forests that are otherwise ecologically suitable in Borneo and Sumatra (MacKinnon 1992; Rijksen & Meijaard 1999; van Schaik et al. 1995). During the 20th century, however, studies of orangutan populations placed far more emphasis on ecological degradation and deforestation as drivers of modern population declines than on the activities of hunting and poaching, for which only anecdotal accounts existed at the time (Meijaard et al. 2011; Schoneveld-de Lange et al. 2016).

This narrative began to change when Marshall et al. (2006) revealed a strong negative relationship between the location of known hunting villages and orangutan densities in East Kalimantan. This was followed by Kalimantan-wide surveys that found an unsustainable number of orangutan killings in each range province, mainly for food and to a lesser degree for self-defense and in response to crop-raiding (i.e., conflict-killings) (Meijaard et al. 2011; Davis et al. 2013). Furthermore, the greatest loss of Bornean orangutans between 1999-2015 occurred within forests that provide suitable habitat for the species – namely selectively logged and primary forests (Voigt et al. 2018). This suggests that direct removals through hunting and/or poaching drove the extreme population decline in these forests, and that these activities appear to be a considerable threat to orangutans in Borneo.

In high-quality habitats, an orangutan population must maintain removal rates below the maximum theoretical growth rate of 2% per annum to be stable and viable in the long term (Marshall et al. 2009c; Utami-Atmoko et al. 2017). Though a few removals each year from a large undisturbed population may not alone induce negative growth rates, the modern reality for most orangutan populations is that significant ecological challenges already exist as a result of legal and illegal logging, mining, drought and fire cycles, agricultural encroachment and infrastructure developments even before additional threats from hunting and poaching are considered. Thus, populations in low-quality habitats are most vulnerable to direct removals due to the low growth rates that exist in resource restricted environments (Singleton et al. 2004). Put simply, a few additional removals each year from a population in degraded and isolated forest patches will lead to its inevitable extirpation (Marshall et al. 2009c).

Respondent-based surveys across Borneo have identified village income from vegetables as a major predictor of orangutan killings (Davis et al. 2013). This relationship is particularly evident in regions where industrial plantations dominate local economies and arable land (primarily within the intermediate rainfall zone), which can limit the ability of communities to generate alternative sources of income from vegetables when financially stressed and lead to an increase in poaching activities (Santika et al. 2017). Smallholder farmers are often displaced from their fields by industrial plantations, leaving farmers that establish new fields more sensitive to crop losses and more likely to retaliate against orangutans (Campbell-Smith et al. 2010). Orangutans are also displaced when large-scale conversions reduce or consume their home range, causing them to forage within anthropogenic landscapes and encounter humans more frequently (Jonas et al. 2017). Thus, the response of both orangutans and humans to extensive land-use changes can contribute to a surge in hunting and poaching rates in and around converted areas, as has recently been reported in East Kalimantan (Abram et al. 2015).

The rate of orangutan killings in Indonesia also escalated in the past during economic crises that drove human communities to hunt wildlife for sustenance and as a source of income (Yeager 1999). In the future, as climatic conditions across Borneo become more irregular, human communities that are displaced from their lands due to unsuitable agricultural conditions may increasingly turn to hunting or poaching wildlife (including orangutans) as alternative livelihoods (Santika et al. 2017). For these reasons, removals due to hunting and/or poaching can make forested habitats unsuitable for orangutans and cause greater harm to a population than can logging at low intensities (Marshall et al. 2006).

3. Habitat Analyses

Across the orangutan's two range countries, Indonesia and Malaysia, the various climate conditions, human activities and environmental protections proximate to and within orangutan habitats form unique combinations of threats for each *Pongo* MP. For example, southern MPs of the Southwest Bornean subspecies (*Pongo pygmaeus wurmbii*) in Central Kalimantan are threatened by extensive habitat loss from industrial logging, agricultural expansion and wildfires that spread from agricultural lands during droughts (Gaveau et al. 2013; Pan et al. 2018; Santika et al. 2017). Furthermore, orangutans in this region experience high levels of conflict with humans that often lead to orangutan deaths (Abram et al. 2015). In comparison, Northeastern Bornean orangutans (*P.p. morio*) in the southern floodplains of Sabah are less threatened by wildfires and human-orangutan conflict than they are by severe habitat fragmentation from the conversion of their forested habitat into oil palm plantations (Ancrenaz et al. 2016b; Santika et al. 2017). The diversity of circumstances that orangutans face across their range requires individual assessments for each MP in order to develop conservation efforts that are informed by current region and threat-specific conditions (Meijaard et al. 2011; Wich et al. 2016).

Estimates of the size, density and distribution of an orangutan population are most commonly based on repeated surveys of orangutan nests along line transects (or plots) throughout the population's range (Mathewson et al. 2008). Once these estimates are available, they can be used to help identify the ecological features that are important to resident orangutans (e.g., preferred food species, canopy contiguity) as well as their preference for certain habitats over time. Alone, however, these assessments cannot identify the factors that influence the distribution or population changes of a given orangutan population. For this, additional information must be collected on (i) the land-use types and habitat conditions that exist throughout the population's range and (ii) the nature and intensity of threats, both long-term and immediate, to the population's viability. This information can be acquired at relatively low cost (Mathewson et al. 2008) and then paired with nest census data to assess the population's long-term viability via statistical modelling (e.g., Utami-Atmoko et al. 2017; Santika et al. 2017). It can also be made available to important stakeholders, such as government agencies that consider land-use proposals within orangutan habitats and NGOs that fund research and conservation initiatives within vulnerable MPs.

Recent studies have integrated data from quantitative (i.e., nest census) and qualitative assessments (i.e., threats and habitat cover) of orangutan populations to model regional trends in their density and distribution over the last few decades (Santika et al. 2017; Voigt et al. 2018; Wich et al. 2016). Using a combination of these data, predictive density models recently identified a potential stronghold in the Karangan MP of northern East Kalimantan estimated to exceed 9,000 individuals (Voigt et al. 2018). This estimate differs substantially from that in the recent Population and Habitat Viability Assessment (PHVA), which placed the number at fewer than 400 individuals based solely on nest surveys from a small area of the potential range (cf. Utami-Atmoko et al. 2017). It is currently unclear which estimate is the more accurate without additional information, but this discrepancy demonstrates the potential value of collecting qualitative data on orangutan MPs in addition to conventional quantitative (population) estimates.

Likewise, analyses of the known remaining MPs of *P.p. morio* throughout Sabah and East Kalimantan suffer from information deficits, specifically data on the threats, habitat conditions and population densities within each unit (Marshall et al. 2007; Utami-Atmoko et al. 2017). Because these factors are required to estimate carrying capacities (K), which are necessary for viability projections, *P.p. morio* remains the only Bornean subspecies for which population trajectories and vulnerabilities cannot be estimated with confidence (Utami-Atmoko et al. 2017). Recent land-cover analyses for the island of Borneo by Gaveau et al. (2016) and Margono et al. (2016) have also reported that the coastal region of East Kalimantan - which supports multiple MPs of *P.p. morio* - lacks forest of any condition (i.e., primary or secondary), contradictory to several governmental reports that identify secondary forest of considerable extent in the region (KLHK 2017; LAPAN 2014; BTNK 2016). Discrepancies and data deficiencies such as these can undermine the collaboration that is necessary between NGOs, government agencies and researchers to maintain viable and interconnected MPs of *P.p. morio*.

4. Kutai National Park

One *P. p. morio* MP whose habitat conditions, densities and vulnerabilities have remained large 'question marks' in population analyses over the past two decades (e.g., Singleton et al. 2004; Wich et al. 2008; Utami-Atmoko et al. 2017) is Kutai National Park (KNP) of East Kalimantan. Up until the early 1970s, the Dipterocarp forests within [and beyond] the present boundaries of KNP were considered exceptionally biodiverse (Pearson 1975; Whitmore 1975; Leighton 1993) and in a near-pristine condition without influence from any large-scale human activities (Leighton 1982; Rodman 1973a). Orangutan poaching was also rare within KNP in the early 1970s because roads were undeveloped and sparse, which restricted access to orangutans and to markets that traded in wildlife, and local villages were mostly populated by coastal Malays who reportedly abstained from hunting orangutans for religious reasons (Rodman 1973b).

Since then, KNP has experienced several periods of large-scale degradation, starting with industrial logging from the late 1960s (Rijksen & Meijaard 1999, p. 227) and later severe droughts and fires during the El Niño years of 1982-83 and 1997-98 (Leighton & Wirawan 1986; Siegert & Hoffmann 2000) and most recently 2015-16. The rapid growth of varied industries around the National Park – namely coal mining, timber, agriculture, oil - also triggered an influx of migrants from nearby Java, Sulawesi and South Kalimantan, many of whom settled illegally along a newly established highway (est. 1991) that cut directly through KNP and have since converted much of the coastal forests to fields of rubber, peppercorn and oil palm (Kiyono &

Hastaniah 2000; Soehartono & Mardiastuti 2013; Vayda & Sahur 1985). As novel practices were brought to the Kutai region, orangutans began to be increasingly hunted and poached for sustenance and profit, which culminated in the regular sale of orangutan meat by a local butcher in the mid 1990s (Rijksen & Meijaard 1999) and the confiscation of more than 100 orangutans from the illicit trade in East Kalimantan between 1992-94 (Smits et al. 1995).

By the late 1990s, KNP was considered the most degraded protected area in Borneo (Yeager 1999; Wells et al. 1999; Delgado & van Schaik 2000) with the vast majority (>95%) of its forests severely burned and/or at best in a secondary/regenerating successional stage (Siegert & Hoffmann 2000; Mori et al. 2000). Following the 1997/98 fires, two primate species (*Nasalis larvatus* and *Presbytis hosei canicrus*) were thought to have been extirpated from the area (Meijaard & Nijman 2000; Setiawan et al. 2009) and KNP as a biodiversity reserve was suggested to be 'lost' based on aerial flight surveys (Jepson et al. 2002).

Despite these interpretations, a wild orangutan population of unknown size persists within KNP forests to this day, possibly by seeking refuge in habitat outside KNP and later returning or by remaining in small isolated patches of unburned riverine forest, similar to how orangutans in the NE region of KNP survived the previous (1983) fire event (see Suzuki 1986). One of the only areas of KNP that has been subject to ecological analyses following the 1998 fires is the orangutan research areas in this NE region of the Park, collectively referred to as the 'Greater Mentoko Area' (GMA) in this report and described below.

4.1. The Greater Mentoko Area

The 'Mentoko' research area was first established in KNP as a 3 km^2 site for orangutan research in 1970 along the NE boundary of the Park, which was and still is demarcated by the Sangatta River (SR). Original [1970] Mentoko habitat was a mosaic of mixed-dipterocarp forest with two structurally distinct zones: an alluvium near the SR with a contiguous multi-strata canopy dominated by Bornean ironwoods (*Eusideroxylon zwageri*) and a hilly inland zone on sand- and mud-stone with a relatively more disrupted, but mature canopy (Leighton & Leighton 1983). Complete dominance of climax species (i.e., dipterocarps) was suppressed by natural disturbances in both zones, namely recurrent flooding up to 2.5 m aboveground that eroded soils in alluvial areas (Campbell 1992) and harsh winds that caused constant tree-falls on the shallow soils of inland slopes (Rodman 1973a). Two small areas along the riverbank, <1% of the study site, had been hand logged of ca. 40 dipterocarps prior to 1970; otherwise, the Mentoko area was at the time “the furthest extent of human habitation along the Sangatta river” (Kurland 1973), situated “far up river” from any human disturbances (Rodman 1973a). The closest settlement was the village of Sengata (Sangatta), located 30 km downriver from Mentoko (Leighton 1982), with ca. 200 inhabitants of Kutai ethnicity (Rodman 1973a).

The second research site in the GMA, now known as the Prevab research and tourism area, was similarly established in 1970 for macaque research along the SR, but ca. 10 km downriver (Fittinghoff & Lindburg 1980). Original habitat of this area had already experienced selective hand-logging at low-intensities by local villagers (ca. 3 trees/ha) mostly within a few hundred metres of the river, after which point primary undisturbed forest could be encountered (Wilson & Wilson 1975). Evidence of old agricultural clearings undergoing secondary succession could be found along either riverbank, and Indonesian timber companies had just begun high-intensity logging operations (>12 trees/ha) inside KNP, ca. 5 km inland from the Prevab area (Wilson & Wilson 1975).

The Greater Mentoko Area (GMA) experienced mechanized selective logging in the early 1970s (6-8 trees/ha) that cut many haul roads through the area’s primary forest (affecting only the southern third of Rodman’s site; Leighton 1982), widespread illegal logging that surfaced without serious obstruction or discipline from forest authorities (Nellemann et al. 2007; Siburian 2008), and two extreme El Niño droughts and related fires. The first of these El Niño events (1982/83) degraded all of Mentoko but only part of the Prevab area (Suzuki 1988); Mentoko suffered partial mortality of canopy trees and near-complete mortality of lianas (Leighton & Wirawan 1986). The second El Niño event (1997/98) devastated almost all of KNP, including most of the GMA, causing a mass mortality of canopy trees and extreme crown-dieback and burn scars to surviving vegetation (Yeager et al. 2003). These areas have since been regenerating naturally in the absence of any major degradative event apart from a third ‘extreme’ El Niño in 2015-16 (Pan et al. 2018) that caused drought stress among canopy trees, especially on dry ridgetops (A. Russon, pers comm).

A recent study from a twice-burnt site in the GMA has described an orangutan population in these regenerating habitats with current diets and activity budgets similar to those found in near-normal habitat conditions (Russon et al. 2015). The nature and intensity of threats to this population – and others throughout KNP – are not well known, and there are also no known

NGOs or programs that address orangutan conservation in the Park beyond tthose provided by the KNP authority (A. Russon pers comm; Wangke 2017).

My report presents a preliminary analysis of the threats to orangutans in the GMA (Figure 1) using habitat assessments around two research areas and observations in the surrounding unprotected areas. The results of this study can build upon the initial foundation of information that is required to develop an appropriate conservation plan for the orangutan metapopulation in KNP.

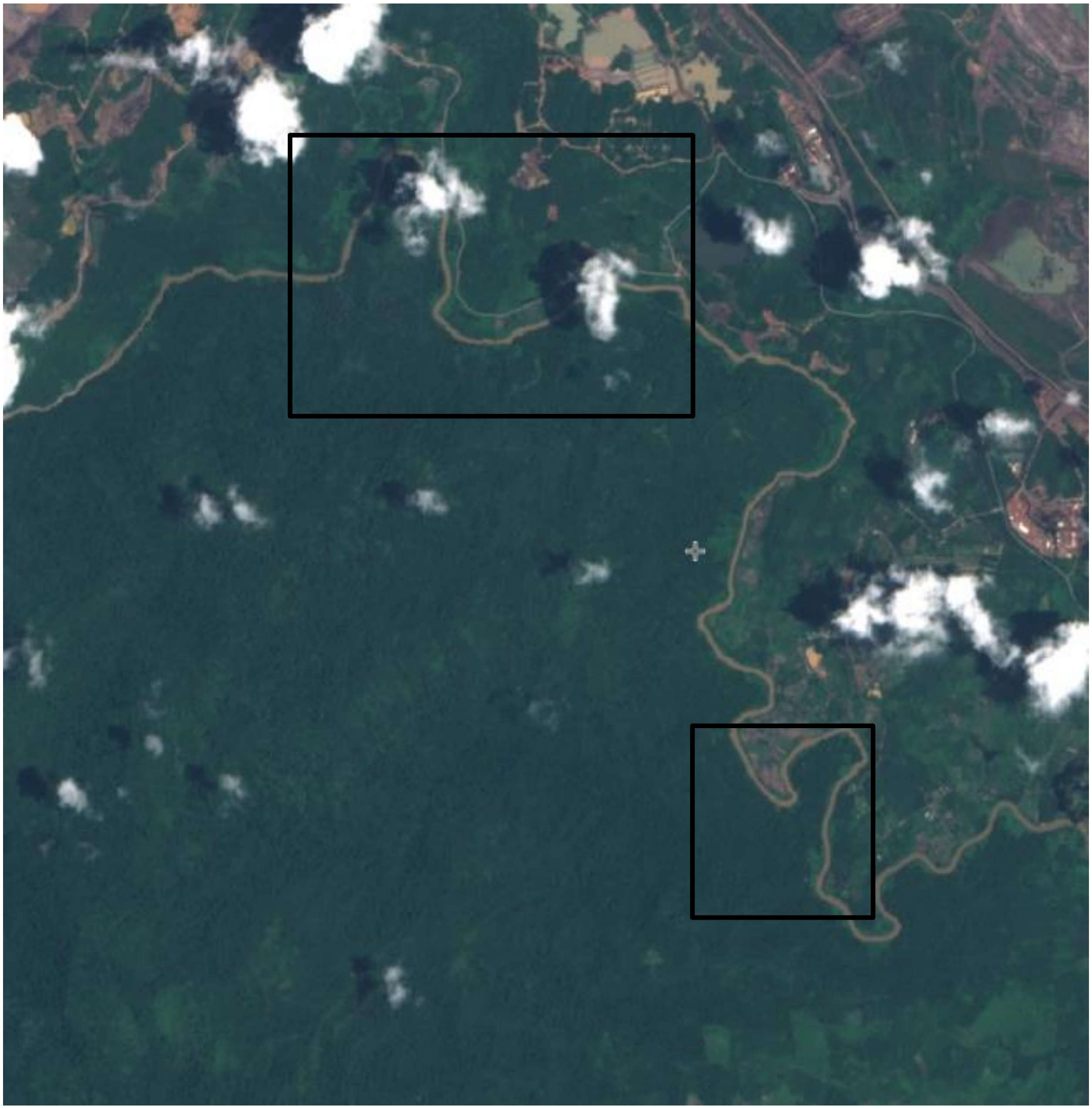

Fig. 1. Satellite imagery of the Greater Mentoko Area in Kutai National Park from Sentinel 2B on March 3 2018. Top box encircles the Bendili research area (south of the Sangatta River); bottom encircles the same for the Prevab research and tourist area. Agricultural clearings visible in bottom right of image in light green.

METHODS

Study Area

All data were collected between May 20 – August 1 2018 within the NE area of Kutai National Park (KNP) in East Kalimantan, Indonesia. Habitat assessments were primarily made along existing 1-3 km transects within two research areas, Bendili (0°33’46” N, 117°26’32” E) and Prevab (0º31’53” N, 117º27’55” E), both located along the southern and western banks of the Sangatta River (SR) which demarcates the northern and northeastern boundaries of KNP, as well as along riverine areas on both sides of the SR where accessible by boat (5-10 km stretches).

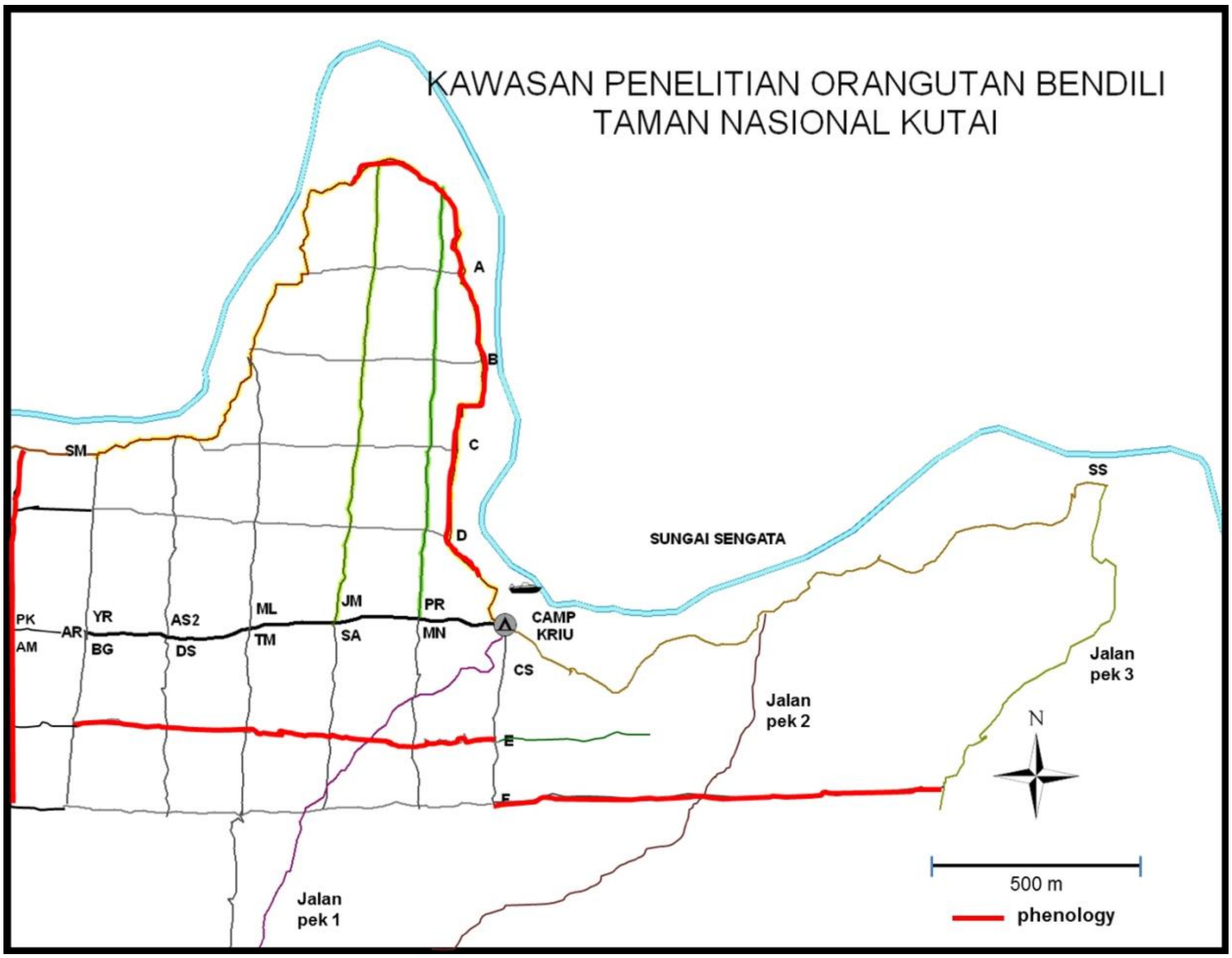

Fig. 2. The Bendili research area in the Greater Mentoko Area of Kutai National Park. Transects surveyed include AR, E, JP, PKAM, C, CS, FT, PEK3, PR, SM and SS.

Bendili is a 4 km^2 lowland site containing regenerating mixed-dipterocarp forest that grades from seasonally-flooded riverine areas at ca. 20 m asl to well-drained upland areas at 220 m asl (Figure 2) (Russon et al. 2015). Bendili shares its western border with the now-defunct Mentoko research site established in 1970 by Peter Rodman (1973a).

Prevab is a 1 km^2 lowland site (0-85 m asl) located ca. 8 km SE of Bendili (or 10 km downriver) characterized by a mosaic of near-pristine and secondary mixed-dipterocarp forest (Ferisa 2014). A research presence was first established at this site in 1970 by Donald Limburg for early field research on crab-eating macaques (Fittinghoff & Lindburg 1980); Japanese primatologist Akira Suzuki later encompassed this site in a much larger study area (eventually 30 km^2) that included also included the Mentoko/Bendili area for his study of orangutan socioecology (see Suzuki 1984, 1994).

Habitat Assessments

Habitat type. The linear transects and non-linear trails (hereafter referred to as transect) ran through three habitat 'types' according to elevational grade: seasonally flooded "riverine" forest along the Sangatta River, "upland" (>20 m asl) mixed-dipterocarp forest on well-drained ridges and ridge slopes (up or downhill), and a "mix" of the two where transects transitioned from flat riverine areas to uphill slopes.

Site transects/trails. Transects were created by the Orangutan Kutai Project for censusing phenology and orangutan nests. Together, the transects in Table 2 covered each of the habitat types present in Bendili and Prevab. Using paper and pen, I systematically recorded the number of logged tree stumps and dead trees within a 5 m radius of each transect as one measure of human disturbance. I also took notes on each of the following along each transect: evidence of recent logging activity (e.g., fresh sawdust, open timber haul trails, sound of chainsaw), signs of extreme droughts (crown dieback), fire damage (burn scars), poaching (e.g., traps, snares), and any other natural or anthropogenic disturbances (e.g., agricultural clearings). Assessments were made when weather permitted (i.e., no rainfall) to ensure visibility. Identity of tree species and time since felling were estimated by experienced research assistants knowledgeable about the area being assessed.

Surrounding areas (outside KNP). Informal observational notes of human activities and forest cover were taken along a 15 km stretch of a public road that passes through the coal mining concession (PT KPC) within 0.5-2 km of the NE border of KNP. This road connects the point of access into Bendili (boating dock on opposite [non-KNP] riverbank) with the city of Sangatta. Satellite imagery from Google Earth Pro was used to identify the extent of logging and mining activities in other areas of the GMA that I did not visit during my study period.

RESULTS

1. Bendili & Prevab

1.1. Vegetation Assessments

The relatively flat alluvial area 10-100 m from the river in the 'thumb' of Bendili, sampled along transect SM, contained a middle canopy of secondary and primary tree species with a few small and large openings from natural tree-falls and illegal logging. Another riverine transect (SS) in eastern Bendili contained many large canopy gaps and areas where forest has been replaced by grasses and bushes. Several large-diameter emergent trees in this area - including at least one fruiting tree of a species that provides preferred fruits for orangutans, *Dracontomelon dao* - stood alone without any lianas or close contact from the crowns of neighboring trees, likely rendering them inaccessible to orangutans. By comparison, the alluvial forest along transect TJ in the Prevab area contained a taller, relatively continuous middle canopy of large-diameter primary species (e.g., *Eusideroxylon zwageri*, *Shorea leprosula*). Along the riverbank areas, those of Prevab are covered by larger stretches of non-forest vegetation (e.g., low-lying grasses and ferns that in some areas stretched 50-75 m inland from the river) than those of Bendili.

1.2. Threats Identified

1.2.1. Natural disturbances. In Bendili, drier hill forest on slopes and ridgetops contained more and larger canopy openings than its riverine areas. Along 1 km of an inland ridge on transect FT, the forest floor was littered with several hundred dead trees (>10 cm dbh), many of which had not yet began their decay. Some had fallen along the perimeter of canopy gaps; many other young trees lay in a pile beneath large-diameter trees. Several areas of this ridge and others throughout Bendili contained large patches of young forest dominated by a secondary tree species, *Macaranga gigantea*. The dry inland forest in the Prevab area (transects P & SL/SP) did not show similar signs of extensive tree death aside from continuous slippage of large trees on the sloped banks of inland tributaries, but perhaps the dry areas of Prevab surveyed were at a lower elevation and on flatter terrain than those surveyed in Bendili.

At the southern border of Bendili, a landslide scar (est. 2017, according to research assistants) extended a few-hundred-meters long, 5 m wide, and 1-2 m deep down a south-facing downslope (transect FT). Its centre was sparsely covered by grasses and a few tree seedlings that had presumably been deposited by nearby mother trees following the slippage. A few fresh (i.e., green) orangutan nests were visible in trees bordering this slide.

1.2.2. Illegal logging. Evidence of illegal logging was found on each of the transects surveyed in Bendili and Prevab, crossing various habitat types and varying widely in degree of damage, intensity and time period. Based on cut stumps of mature trees (>10 cm dbh), I counted 65 logged trees over 8.5 km of transect in Bendili and 8 logged trees over 5.5 km of transect in Prevab (Table 2). Most stumps at Bendili - and all stumps at Prevab - had been logged more than a decade prior, according to research assistants and observations of the maturity of sprouts from the stump, decay of wood, and overhead canopy structure. Intensity ranged from a high of 15 tree stumps along a 0.5 km downslope in Bendili (PR) to a low of one tree along a 3 km riverine trail in Prevab (TJ). Tree species logged included Bornean ironwood (*Eusideroxylon zwageri*), dipterocarps, and Arau trees (*Elmerillia tsiampaca*; Kessler 1994), all dbh 0.5-1.5 m.

Table 2. Degree of illegal logging along transects in Bendili and Prevab.

Study Site	Transect (length in km)	Habitat Type	# Felled Trees
Bendili	AR (0.5)	Upland	3
	E (1)	Upland	1
	JP (0.5)	Upland	5
	PKAM (1)	Upland	2
	C (0.5)	Mixed	3
	CS (0.5)	Mixed	4
	FT (1)	Mixed	3
	PEK 3 (1)	Mixed	11*
	PR (0.5)	Mixed	15
	SM (1)	Riverine	7*
	SS (1)	Riverine	11
Prevab	TJ (3)	Riverine	1
	P-SM (0.5)	Mixed	3
	SL-SP (2)	Upland	4

* Recent logging within one year of study period

In Bendili, two stumps appeared to have been felled within a year of the study period, including one large Arau tree (see above) and one large ironwood (*E. zwageri*). The ironwood tree, an emergent (>15 m tall) within 100 m of the riverbank, struck (or pulled down) and killed several nearby trees, creating a large canopy gap that had not filled in by the time of my study. The ground was covered with many improper/imperfect cut planks and a layer of decaying sawdust 2 m wide. Although evidence of recent logging was not found along the transects surveyed in Prevab, an area within KNP just south of Prevab is known to actively experience illegal logging at high intensities (P. Kuncoro, research team member, pers comm). I did not visit this site as a safety precaution; satellite imagery reveals extent and size of recently logged areas (Figure 3).

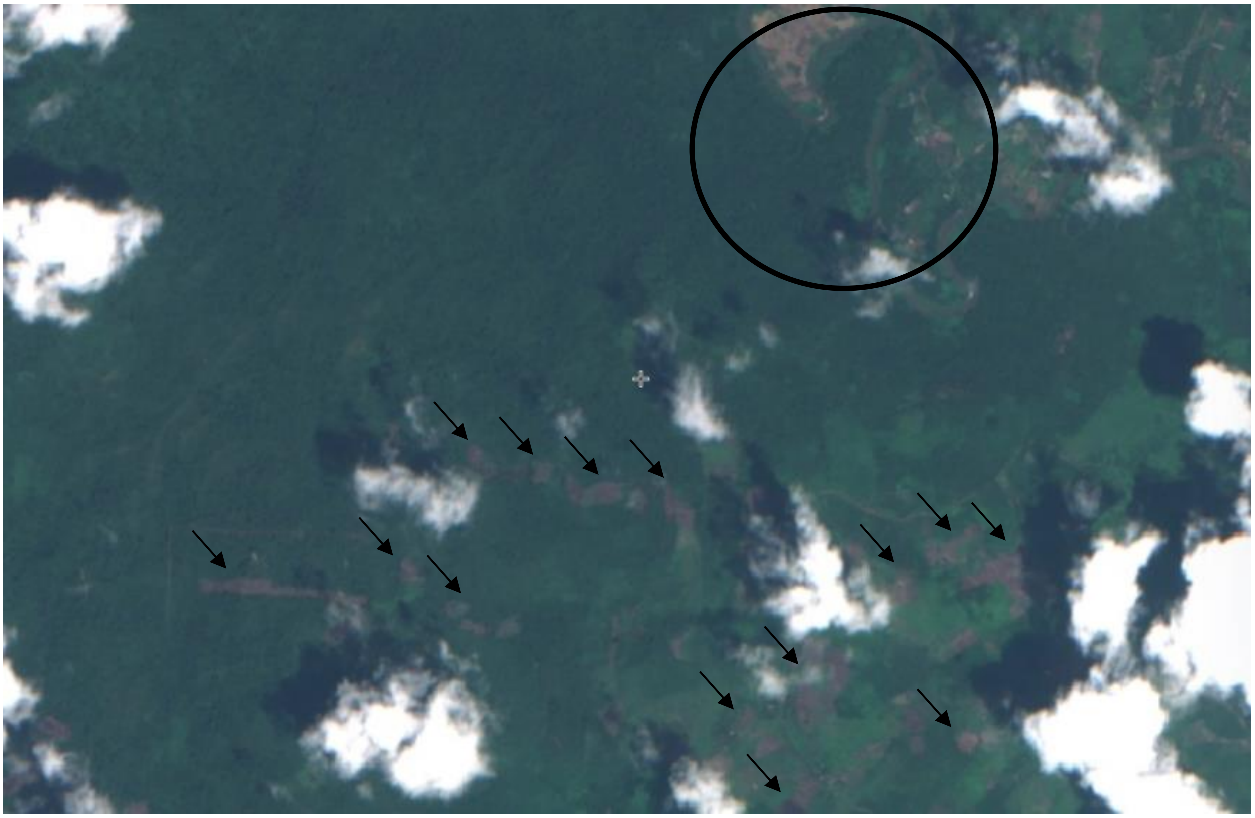

Fig. 3. Satellite imagery of the extent of illegal logging along the southern border of the Greater Mentoko Area, just south of the Prevab area (encircled). Recently logged patches are indicated by arrows along the bottom half of the image in brown. Image from Sentinel 2B on October 29 2018 from Global Forest Watch.

During the study period a logging site was discovered just beyond the western boundary of Bendili (not included in Table 2), within Rodman's original Mentoko research area. This was initially detected by the sound of a chainsaw operating for a number of hours one morning. Directly after the incident was reported to a KNP authority, the sound promptly ceased for the day. A team of KNP rangers and forest police visited the Mentoko area three days after the initial report to locate the logging site, apparently a typical time frame for the KNP office to coordinate the visit with the forest police and arrange transport across the river. The team reported finding 20 logged ironwood trees (half old, half recent).

Several days after their visit, we visited the site to examine the damage. The main site was reached by walking south from the riverbank along a narrow haul-trail for 400 m. The ten 'old' logged stumps skirted this trail, and several strips of cleared land branched from the trail where some of the recently-logged ironwood had been felled, leaving behind fresh sawdust and rejected boards (Figure 4). Other ironwood planks were laid over waterlogged areas of the trail for transporting timber back to the river. The main logging site, ca. 200 m^2 in size, was entirely open and covered with dead branches, fresh sawdust, cut planks and a few ironwood trunks (1.5 dbh) that still held a substantial amount of timber, suggesting either that the operation had been abandoned or simply that the loggers had met their quota. The substantial ground-cover made it impossible to count the number of tree stumps accurately, but we estimated roughly 20 felled ironwood trees between the river and this logging site (half old and half recent). Another narrow trail continued south beyond this logging site; it may have led to additional logging, though we did not follow it.

Fig. 4. Logging site discovered west of Bendili, ca. 400 m inland from the Sangatta River. Top image depicts leftover woody debris in 200 m^2 site, bottom shows canopy opening created by illegal logging at this site.

1.2.3. Fire. Several transects at both sites revealed signs of past fire damage. In Bendili this was most notable along a 1 km slope (PKAM) running inland from the river where almost half of the 83 dead canopy trees were noticeably burnt. Damage ranged from surface singes (i.e., charred bark) to completely burnt tree cores. Along a drier inland ridge (FT), only a small portion of the hundreds of fallen canopy trees on the ground were visibly burnt. Burned trees were also discovered along the drier, hilly transects in Prevab from past wildfires, some of which were still standing despite burn scars up the length of the tree.

Two very large Kapur trees (*Dryobalanops sp.*) with extensive burn scars up their entire trunk, both >15 m tall (dbh 1 m and 1.5 m), were found along the PKAM inland transect in Bendili. The larger of these trees fell during the study period and revealed two interesting features across the length of its trunk: burn scars that reached the heartwood at its base but only singed the bark over the rest of its trunk, and steel nails up the entire trunk that had been hammered in at a downward angle. It is apparently a common local practice to collect honey from these forests by starting a fire at the base of a host tree to 'smoke' the bees in their hive, which can disarm the colony's defensive response. The collector is then able to insert a series of nails up the length of the tree to reach the hive and retrieve its honey. The research assistants believed this to be a likely explanation for the steel nails in one of these Kapur trees.

1.2.4. Illegal gardens. In Bendili, an old 3 x 30 m agricultural clearing was found within 20 m of the SR near the site's eastern boundary. Given the closed overhead canopy and absence of cut stumps in the area, it is likely that only young trees and understory vegetation were removed to establish this strip. Coffee seedlings, sapling and trees were scattered in with a sparse mix of tree seedlings and gingers. This strip was discovered by the Bendili research team in 2011 with hundreds of recently-planted coffee seedlings (A. Russon, pers comm). After the research team informed the local KNP office, Park authorities promptly removed all seedlings from the strip. A few seedlings and/or seeds must have been missed given the sparse coverage of coffee plants over seven years later. As far as the research team knew, the perpetrator(s) had not returned to the site since it had been stripped of its coffee seedlings, and the two mature trees are now fed upon by small animals in the area.

1.2.5. Poaching & killings. Evidence of poaching (e.g., snares, traps, hunters) was not observed along any of the transects surveyed in Bendili or Prevab during the study period. However, poaching activities have been evident in Bendili in recent years. For example, in early 2017 the Bendili research team (Orangutan Kutai Project) discovered a homemade pig bomb (or 'bom babi') that had detonated along a forest transect and left behind a pool of blood from its victim, who was nowhere to be found upon discovery of the device (Figure 5). The target species was likely a bearded pig (*Sus barbatus*) or a sambar deer (*Cervus unicolor*) that are known to live in the GMA, although the victim in this case could have been any number of animals. Years prior, the research team also removed dozens of snares from the ground while establishing research transects in several areas of Bendili.

Fig. 5. Photograph of detonated pig bomb (or 'bom babi') discovered in the Bendili research area in 2017 by the Orangutan Kutai Project. Blood of victim visible to the right of the bomb.

1.2.6. Tourism. In Prevab - one of the few posts within KNP that is open to tourists – some actions by tourists during their observation of an orangutan family, which included a 27 year-old mother (Labu) and her daughters, 7 year-old juvenile-adolescent (Langit) and 2 year-old infant (Luna), were concerning as potential health threats to the focal orangutans and to the greater orangutan population in KNP. At one point, the group of observers - including Park staff, tourists and researchers – totalled eleven individuals for an extended period of time. Some that had been observing the orangutan family prior to my arrival continued their observation even after my exit, some 90 minutes later. Individual groups of tourists and their guide joined and left the 'observing group' several times over this time period. Respiratory masks were not worn by - or made available to - any observer, and unsupervised tourists frequently came within 5-10 m of the family as their guides talked and laughed loudly with one another some 10 m away. One tourist smoked and disposed of cigarettes within 15 m of the family without notice or correction from their guide (as prescribed in Macfie & Williamson 2010).

2. The Sangatta River

2.1. Access

The villages along the western periphery of the Sangatta enclave (area excised from KNP to the district of Sangatta for public interest) represent the closest 'main' human dwellings around the GMA, save for a few illegal settlements opposite Bendili and Prevab discussed below. The land across the SR to the north of Bendili is the Kaltim Prima Coal (KPC) open pit coal mining concession, which covers close to 85,000 ha of land. Several mining scars (including one pit lake[1]) and a paved and dirt road (Jalan Poros Sangatta-Rantau Pulung) flank the eastern portion of the SR around Bendili, all within 200 m of Bendili's riverbank. This road was built by KPC in the 1990s to support its mining operations; it now connects the subdistrict community of Rantau Pulung [24 km to the NW] to the city of Sangatta [15 km to the SE] and is used extensively by both communities. River rapids and rock formations along Bendili's eastern border limit up- and down-stream travel by boat, making this road the major current means of vehicular transport from Sangatta to Bendili.

Closer in proximity to Sangatta and its peripheral villages, Prevab can be accessed by a 4 km boat ride up the Sangatta River from the village of Kabo Jaya or by following a dirt road to the riverbank opposite Prevab and crossing the river by boat. The land across the river from Prevab falls within the Sangatta enclave.

2.2. Condition of Riverine Habitats

Extreme floods and heavy rains have severely eroded both sides of the SR around Bendili and, in several places, caused a collapse of the riverbank and regular slippage among trees that border their edges. A continuous perimeter of reeds, grasses and low-lying bushes grows

[1] A pit lake is one endpoint option of open-pit mines and involves flooding the mined pit with water to create an artificial reservoir.

between the shoreline and the first trees/shrubs along both riverbanks. This perimeter has expanded beyond a thin strip (in the best of cases) to fill in the many heavily degraded areas along the northern (KPC) riverbank and several flat areas along the southern (Bendili) riverbank where forest starts 5-50 m from the shoreline. Based on area maps by Suzuki (1989), most of these degraded areas were cleared many decades ago by shifting agriculturalists and later left to revegetate, only to be succeeded by non-forest vegetation. Some areas identified by Suzuki (1989) as unburnt forest but by myself as non-forest patches, particularly on the southern (Bendili) riverbank, may have been colonized by invasive vegetation following the destruction of the 1998 fires.

Inland from the shore, habitat conditions on the KNP vs. KPC side of the river are strikingly different in concert with the legal protections they receive. Most of the immediate edge of Bendili's 'protected' forest is made up of shrubs, small trees and old standing deadwood covered in epiphytes and woody climbers; in some areas sharply and in others gradually, this edge transitions to a taller canopy of primary and secondary trees punctuated by several small-crowned emergents. From the river's vantage, this border of forest is relatively continuous without noticeable gaps. Many new and old orangutan nests were visible in the canopy trees along this border, especially in *Dracontomelon dao*. At no point did the canopy or any one tree extend past the shoreline, nor did any tree along this edge appear tall enough to create a cross-river bridge for orangutans to cross if it fell.

In contrast, the riverine border across from Bendili, which is part of the KPC coal concession, is heavily degraded, especially along the eastern half that lies between the Sangatta River and the road. Land cover ranged from stretches of completely cleared land to small regenerating areas with a low canopy of secondary trees. Several sloped areas along the riverbank had been obviously cleared to facilitate human access to and from the river and the Park itself; another area with large patches of bamboo had been plundered of their shoots and canes, leaving behind a thick layer (0.5 m) of dry cuttings and dead branches that extended to the shoreline. At the eastern edge of the river section surveyed, multiple hillsides ascending from the riverbank had been excavated (for softstone and sand) and left bare, and a narrow haul road connected excavation area with the main road. Satellite imagery shows these hills were covered by forest only four years prior (Figure 6).

Fig. 6. Satellite imagery of the excavated hillsides along the eastern stretch of the Sangatta River around Bendili, four years apart: left shows intact hillsides in 2014 (June 30; Landsat 8), right shows excavated hills in 2018, indicated by arrows (March 3; Sentinel 2B).

Along this riverbank (KPC-side), six smallholder farms were identified between stretches of degraded forest and cleared land; these mostly grew oil palms, but a few grew a mixture of domestic fruits (e.g., banana, jackfruit, coconuts) and oil palms. Only one of these farms appeared to have housing and occupants that were regularly observed clearing the forest adjacent to them; users of the other plantations were evicted by KNP authorities 2-3 years prior to my study period on the grounds of squatting (illegitimate land tenure) (A. Russon, pers comm). Decrepit concrete buildings also sat in the middle of a clearing between the road and riverbank; their owner was evicted at the same time, for the same reason (A. Russon, pers comm).

Despite the poor condition of the riverine habitats opposite Bendili, a considerable amount of degraded forest still remained north of the river on KPC-owned land, particularly in areas further away from the road and river. Orangutans in the GMA are able to cross certain points along the SR in the dry season according to my observation of a cross-river rock formation at the start of the dry season and previous reports of orangutans crossing shallow areas of the SR (Muklhisi et al. 2015). Additionally, separate sightings of orangutans on the KPC side of the river, including a flanged male in a patch of regenerating forest (observed by myself) and at least one other adolescent male in a riverside plantation (observed by our local driver), have confirmed that orangutans range in the unprotected habitats outside KNP and north of Bendili (also see Niningsih 2017).

Apart from similar signs of erosion and collapsing riverbanks, the condition of riverine habitats between Prevab and Kabo Jaya are quite different from those around Bendili. The recession of forest, riverbank erosion, and expansion of invasive vegetation on the 'protected' (KNP) riverbank along this stretch of river were much more severe and common compared to those around Bendili. Where the tree line approached the riverbank, forest structure was considerably more degraded (shorter, discontinuous canopy) than the riverine forest around Bendili. The most extreme case of forest destruction along this riverbank was directly across-river from Kabo Jaya where ca. 20 ha of forest stretching 500 m inland had been replaced by barren fields and a large garden of oil palms. In addition to this large clearing, one other smallholder palm oil plantation and one square clearing ca. 5 ha in size were identified in between stretches of scrubland and degraded forest on the KNP/protected side of the river. Mature banana trees also sporadically dotted certain stretches of this riverbank inside KNP, probably remnants of agricultural gardens whose owners have since been evicted.

On the opposite (non-protected) side of the river, nearly all of the 4 km of land between Prevab and Kabo Jaya had been cleared or left in a heavily degraded state. Seven separate smallholder farms of mostly oil palm and domestic garden plants (e.g., beans, corn) and numerous barren fields abutted the river; a number them also contained housing and boats at the river's edge with regular occupants. Given the degree of degradation on both sides and the width of the river this far downstream, a natural cross-river bridge from a sudden tree-fall appeared to be much less likely along this stretch of river than around Bendili.

No orangutan nests were identified on either side of the river between Prevab and Kabo Jaya, contrasting the abundance of nests that were visible on both sides of the river along this stretch prior to the 2015/16 drought (A. Russon, pers comm).

2.3. Other Observations

Two separate observations of human activities on the river around Bendili generated cause for concern for their environmental impact. The first involved a group of men in a vehicle that was encountered near a riverside dock (KPC side) who claimed to be conducting research for a future river-rafting project on the SR. Following this encounter, a short distance upriver we met another group of men docked on the opposite riverbank (Bendili/KNP side) resting beside dozens of wood planks on the shore. Although we did not communicate with the second group, we presumed these occurrences represented a coordinated effort at transporting logged timber out of protected forest. The second incident concerned fishermen that were observed applying ‘decis’ - a commercial insecticide highly toxic to aquatic animals - to the SR for the purpose of harvesting the river’s shrimp (*Caridina spp.*); decis paralyzes the shrimp so they wash up along the downstream shore to be collected. The use of poison in fishing practices on the SR is illegal for a number of reasons – not the least of which is Sangatta’s reliance on this river for freshwater – but a report of this incident to a KNP authority later in the day was not investigated because we could not provide pictures of the scene.

3. North of Bendili

Much of the orangutan habitat that once existed north and east of the GMA has disappeared due to industrial mining, legal and illegal logging and rapid human population expansion over the past five decades. The most extreme example of this loss was unmistakable from the roadside between Sangatta and Bendili, where, at many points, the southernmost scars of KPC’s coal mining came within metres of the road (Figure 7). Current satellite imagery shows these open-pit scars extend north almost continuously for 12 km and covered an east-west distance of 26 km above northeastern KNP. KPC’s active mining operations, including open-pit and strip mining, and one multi-storey administrative building were visible at four separate points along this northern road, all within 1.5 km of Bendili’s riverbank. Artisanal (illegal) mining was also evident along the roadside, indicated by the small-sized excavations that were secluded from larger scars; this included several defaced hillsides near Bendili from which locals extracted large rocks and sand to be used in construction projects (P. Kuncoro, pers comm). Upon previous excavation of one of these hillsides, rock debris fell into and blocked the flow of the SR (A. Russon, pers comm).

Fig. 7. Satellite imagery of industrial mining north of the Bendili research area over two time periods: left is two months before my research period (March 3 2018; Sentinel 2B), right is one year later (April 12 2019; Sentinel 2A).

Over the dozen or so trips I made across this northern road, each time I observed [generally young] locals harvesting grasses, ferns and foliage along the roadside and transporting bundles back to town to be fed to livestock. Piles of discarded garbage were also regularly observed along the roadside, sometimes burning or smoldering and often dangerously close to grasses and patches of degraded forest. Many roadside areas were visibly burnt, including one blackened slope with a coal seam still smoldering from a previous fire.

DISCUSSION

1. Threats Identified

Orangutans in the GMA of KNP currently live in habitats that differ in many ways from the conditions that were described as "exceptionally favorable" in the early 1970s (Rodman 1973a), in terms of both the physical environment and the relative influence of humans within and around it. A great deal of this change occurred over the latter half of the 20th century from widespread logging, natural resource extraction, and extreme El Niño droughts and fires, but the results presented in this report reveal numerous factors that continue to degrade this protected area and threaten the viability of its resident orangutan population.

1.1. Logging

Across 8.5 km of transects surveyed in Bendili, only two large hardwood trees – one arau and one Bornean ironwood – had been recently logged (within one year); the remaining 63 stumps counted appeared to have been logged several years [or in many cases, decades] prior. Each of the 8 stumps identified along 5.5 km of transect in Prevab was at least a decade old; some may even be among the 55 stumps counted across 16 ha of the Prevab area more than 45 years prior by Fittinghoff & Lindburg (1980). However, active logging operations should not be considered rare or absent from the GMA based on these counts; numerous sites beyond the boundaries of Bendili and Prevab were actively logged during the study period according to my observations and satellite imagery.

I visited one of these sites, near the western border of Bendili in Rodman's original Mentoko area, just days after 10 large ironwoods had been extracted by a team of illegal loggers; the 200 m^2 logged area had no canopy or living trees and was left with a thick ground-cover of combustible deadwood, sawdust and cut planks. Another logging site was directly observed in the non-KNP riverine forest at the northern border of Bendili, where a smallholder oil palm farmer actively cleared the forest beside his plantation; several other sites (e.g., near the southern border of Prevab) were identified as recently-logged using satellite imagery. Each of these locations is relatively distant from areas frequented by research activities (in Bendili and Prevab) or by KNP authorities and (in Prevab) tourists– a pattern that likely represents intentional avoidance by illegal loggers to evade detection. The low number of recently logged trees in Bendili (and none in Prevab) therefore likely reflects the protective influence of research activities and (in Prevab) tourism more than the current state of illegal logging in the GMA.

The way in which the 'Mentoko' logging site was discovered and dealt with by KNP authorities during the study period provided a brief glimpse into current processes that underlie forest monitoring and law enforcement within KNP. First, the cessation of the chainsaw heard within KNP's boundary minutes after it was reported to a KNP authority (via text message) brought to mind previous reports of cooperation between illegal loggers and KNP/regional authorities for financial gain during the early 2000s (see Arnscheidt 2009; Purwanto 2005). Alternatively, the illegal logger(s) may have been tipped off (also via text) by a project research assistant at the time of the report, or the timing of these events could simply have been coincidental. The second concern was around the slow response time of the KNP authorities (three days after the initial report), which was purportedly both necessary and normal given (a) their obligation to coordinate any investigation of illegal logging in the National Park with the provincial forest authority (BKSDA) and (b) their dependence on community members or (in this case) the research team to provide river transport. Regardless of whether or not the illegal logger(s) were made aware of the impending inspection, this lag likely afforded them ample time to abandon or complete their operation and leave the area before authorities arrived. If these aspects of Park management are indeed ordinary, even honest investigations may prove ineffective at curbing illegal logging within KNP.

In my Results I describe a string of encounters with two groups of men on the Sangatta River around Bendili, one waiting by a boating dock claiming to be river-rafting entrepreneurs, the other a short distance upriver returning with a boat-load of timber; these occurrences were presumed to reflect yet another instance of illegal logging in this area. The prevalence of timber theft in KNP has been discussed in Siburian (2008), who described a major surge in illegal logging throughout the Park by entrepreneurs, migrants and locals following the catastrophic fires of 1998. An estimated 7,280 m^3 of timber was poached from KNP by 1999; by 2001, this rate had reached 158,032 m^3 (Siburian 2008). In his report, Siburian also described the influence of a cross-island network that sourced, moved and traded timber stolen from protected areas throughout Indonesia. By 2008, this network regularly exported stolen timber out of KNP using transport trucks that bore East Java license plates and a top-layer of bananas to disguise the illicit load (Siburian 2008).

Logging within the GMA presents a major threat to resident orangutans for a number of reasons. For one, the main targets of illegal logging in KNP – Bornean ironwoods – naturally enrich orangutan habitats with safe and abundant nesting sites (Alqaf et al. 2016; Kabangnga et al. 2010; Niningsih 2009, 2017; Rayadin & Saitoh 2009; Sayektiningsih & Rayadin 2011) and key orangutan foods produced by climbing- and strangling-figs (Ferisa 2014; Niningsih 2017; Russon et al. 2015), the latter of which preferentially select ironwoods as hosts for their structural support (Leighton & Leighton 1983). The removal of these trees from logged areas may lower the selection of foods available to orangutans in the GMA and require orangutans to select less preferred nesting trees.

Moreover, considering that lowland forests in eastern Borneo are already highly susceptible to fire during El Niño droughts (particularly extreme events, made worse and more frequent by global warming), one of the main effects of future logging in these forests will likely include increases in the intensity of – and destruction caused by - future fires. This is because in addition to the high fuel load that logging creates in the form of woody debris (Ahmad 2001; Pfeifer et al. 2015) and fire-sensitive vines that proliferate under canopy openings (Fox 1968; Appanah & Putz 1984), ironwood trees are also highly drought- and fire-resistant (see Goldammer & Siegert 1990; Hastaniah & Kiyono 2000; Leighton 1984; Tagawa et al. 1988). Thus ironwood trees play an important role in protecting burned forests from invasion (and replacement) by non-forest or more fire-susceptible vegetation following fire events. The combination of these effects makes forests in this region that experience even low-intensity logging much more vulnerable to catastrophic fires (as opposed to cooler fires in undisturbed or partially recovered forests; Siegert et al. 2001) and less capable of regenerating following fires.

1.2. Drought & Fire

The multitude of recently-fallen trees and canopy openings along a dry ridge in Bendili gave some indication of the damage caused by the most recent extreme El Niño drought in 2015/16. The resultant canopy openings in this area have allowed heavy rains that followed the drought to destabilize the shallow soils, which may have triggered the recent landslide along this ridge that cleared a few-hundred-meter long strip of downslope forest and removed several soil layers (1-2 m deep) that hold crucial regenerative elements, such as the soil seed bank, organic matter and mycorrhizal fungi (Whitmore 1984). Considering this damage, and the sparse coverage of young seedlings and grasses on this trench after at least one year of regrowth, it may take decades before this strip regains any canopy cover or habitat qualities that can be of use to orangutans (i.e., resources, nesting sites). A similar decades-old landslide scar in Bendili remains in the early stages of regeneration.

Now more than ever, analyses of the threats to orangutans and their habitats in the GMA require consideration of the fire sources that exist in this region given the proliferation of human activities in and around this protected area and the expectation of stronger climatic episodes in the near future. The potential ignition sources that I observed first-hand in this area include cigarette smoking by research assistants, tourists, guides and illegal loggers[2]; burning of garbage at research sites (controlled) and roadsides (uncontrolled); actively burning coal seams; and local honey-collecting practices. Most of these ignition sources have yet to be directly connected[3] to

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[2] Discarded cigarette pack discovered in pile of woody debris at logging site west of Bendili

[3] But direct causes of wildfires in Indonesia are severely under-researched (see Vayda 2006, 2010)

wildfires in neighboring forests; the exception is burning coal seams, many of which are found in East Kalimantan (Whitehouse & Mulyana 2004) and have been observed on numerous occasions during severe droughts (e.g., Bird 1995; Goldammer & Siebert 1990; Jayasankaran & McBeth 1994; Mori 2000). Other sources of fire in this region have been recorded (Dennis et al. 2005; Vayda 2010), e.g., use of fire as a weapon (arson) by individuals seeking retaliation or by land operators interested in acquiring land at a low price, and as a land preparation tool by smallholder farmers and large landholders despite prohibitions on burning during extreme droughts.

Although fire-use by plantation operators was not directly observed in the present study, each of the main ethnic groups in Sangatta - Kutai, Dayak, Bugis (Sulawesi) and Java – traditionally use fire to prepare land (Bismark & Sawitri 2014), and agricultural burning has long been considered one of the main culprits of forest fires in this region (Goldammer et al. 1996; Leighton & Wirawan 1986; Lennertz & Panzer 1983; Malingreau et al. 1985). Most authors (including those cited above) posit the use of fire to clear/prepare[4] land as the only source of fire associated with agricultural practices, but farmers in Indonesia regularly use fire for many other purposes, such as to eliminate pests (e.g., rhinoceros beetle, palm rats) and disease (oil palm root rot) (Simorangkir et al. 2002); burn agricultural wastes (Murdiyarso & Adiningsih 2003; Schweithelm & Glover 2006); and rejuvenate nutrient-depleted soils mid-cycle (Ketterings 1999). In addition, every smallholder oil palm plantation in Indonesia will require replanting before 2040 in order to remain productive (Glenday & Paoli 2015) and, without subsidized alternatives or training, the majority of them will likely continue to use fire as a cost-effective means to clear and fertilize their land. Fire represents a major threat to the GMA and other forests that neighbor oil palm plantations over the next 20 years. The threat of fire is therefore not limited to the initial development of agricultural fields, but persists through the life of the plantation/garden and stems from various uses.

Vayda (2010) also described a forest fire in East Kalimantan during the 1997/98 El Niño drought that was set by transmigrant banana and cocoa farmers to access fertile land after losing their crops to the severe drought. This is a particularly apropos example of fire threat to forest in

[4] Burning vegetation on deforested or forested land is falsely believed to be the most cost-effective method for farmers to 'clear' land and 'prepare' it for agricultural planting, the latter of which results from the deposition of nutrient-rich ash into the soils.

the GMA for several reasons. For one, a large number of active smallholder farms exist at the immediate border of the GMA, as well as several within the protected area, which positions human livelihoods in direct proximity to regenerating forests. This is especially true around Prevab, which is bordered entirely by smallholder oil palm plantations, local gardens and barren fields – separated only by the Sangatta River. Secondly, the financial vulnerability which drove the farmers in this example to burn down a forested area also burdens the majority of Sangatta households due to their deep-rooted reliance on (a) the market price and local production of coal, which plummeted in 2014-2015 and lowered the average income in Sangatta (Rahman 2017) and (b) the flow of the Sangatta River for drinking and agricultural water. During the severe 1982-83 drought, when only 20% of rain-fed fields in East Kalimantan yielded crops, several villages throughout the province slipped into poverty and required emergency food shipments (Mackie 1984). As large consumers of coal (especially China) begin to transition to renewable sources of energy, as coal reserves in East Kalimantan decrease, and as regional climate patterns become more irregular and extreme, the forests of the GMA will likely grow increasingly vulnerable to fires that are set to gain emergency access to arable land. The threat of this scenario could surface much sooner considering that the 30-year mining permit held by KPC expires in 2021, and, even if it is extended, its concession area is projected to be depleted of coal by 2041 (Niningsih 2017). This depletion could spur an economic crisis for residents in this region and place significant pressure on forest in the GMA.

A review of the available literature points to a few notable factors that may have saved the orangutan population in the GMA from extinction when faced with extraordinary challenges over the past five decades. When the forests of Mentoko first burned during the extreme El Niño of 1982/83, the only areas to escape major drought and fire damage were the forests around perennial rivers and streams (Berenstain 1986; Suzuki 1984) on account of their wetter soils and greater representation of drought- and fire-resistant ironwood trees (*E. zwageri*) (Leighton & Wirawan 1986). These riverine patches provided refuge to orangutans displaced from the surrounding burnt and drought-stricken areas which suffered from low food productivity (Suzuki 1986, 1988) and delayed mortality of some trees for a number of years after the fires (Leighton & Wirawan 1986). Despite the cataclysmic scale of the 1997/98 drought and fire event (Rijksen & Meijaard 1999, p. 229), small patches of riverine forest in this area once again escaped burning (Toma & Simbolon 2000) and likely provided similar refuges to displaced orangutans.

It is also likely that some of the orangutans escaping these fire events crossed the Sangatta River via shallow or dried basins and fled north into what was then a mixture of degraded forests and shifting agriculture (prior to conversion by industrial mining). In fact, 75 orangutans sought refuge in the industrial (KPC) mines east of this area after fleeing the 1998 fires (compared to an average of 6.5 orangutans per year in the subsequent years of 1999-2001 & 2003), all of which were then translocated to nearby forests (Niningsih 2017). The GMA received 51 of these orangutans, which may have to some extent tempered the recent loss of individuals (and genetic variability) from this population even if only a small portion of those translocated survived the harsh conditions. Reports from both fire events also found that displaced orangutans sought refuge in the neighboring city of Sangatta where they nested in farmer's fruit trees, and in the industrial timber plantations around KNP where they exploited the cambial tissue of Acacia trees (Boer 1989, 1999). During the 1998 event, hundreds of adult orangutans fleeing the fires in East Kalimantan were slaughtered by villagers who were defending their land (Barber & Schweithelm 2000).

The exceptional resilience displayed by this orangutan population through major fire events in the past is not expected to persist through another major wildfire event in this region despite the significant regeneration of forested habitats in the GMA since the last major fires (Ferisa 2014; Krisdijantoro 2007; Niningsih 2017), the impressive trajectory of orangutan behaviours and diets toward near-normal conditions in such habitats (Russon et al. 2015), and the identification of more than 70 orangutans within the two research areas of the GMA by 2013 (Ferisa 2014). This expectation is based on the extensive changes to land-cover and forest conditions in this region since the last major fire event that have eliminated several of the key elements used by this orangutan population to evade extinction in the past.

Specifically, ongoing illegal logging in this protected area has, for one, substantially reduced the dominance of Bornean ironwood trees which previously protected riverine habitats in the GMA from severe drought- and fire-damage (Leighton & Wirawan 1986). Nearly all of the forested habitats that once existed north of the GMA have also been logged and/or converted to industrial mining in recent decades, which represents a significant change to the refugial areas outside of the GMA that were previously available to – and likely used by – this orangutan population during previous fire events. So too has the southern border of the GMA continued to lose protected forest to illegal logging and agricultural expansion. These activities have likely been the source of the numerous fires in this encroached area over the last five years (GFW 2019). Together with the many smallholder oil-palm plantations that currently line the riverine border of the GMA, there are now more ignition sources in close proximity to this protected area than ever before. Lastly, the forests of the GMA currently contain many sources of combustibles, in the form of the (i) woody debris and abandoned timber left behind in logging sites; (ii) higher proportion of pioneer trees that are naturally more combustible than climax species (Kartawinata 1980); (iii) fire-sensitive perimeter of non-forest vegetation (low-lying grasses, weeds and bushes) that skirts forest along the river; and (iv) abundance of regenerating forests dominated by secondary tree species, e.g., *Macaranga gigantea*, which regularly shed their large, thick leaves to accumulate in piles on the forest floor, particularly during droughts. These conditions have set the stage for future fires in this area to reach cataclysmic scales similar to or potentially greater than the 1998 event that levelled nearly all protected habitats available to this orangutan population.

The three major drought and fire episodes in KNP – namely 1997/98, 1982/83 and 2015/16 in order of severity[5] – have all occurred during years in which two exceptionally strong climate events have converged to create what is known as a 'super El Niño' (see Chen et al. 2017; Pan et al. 2018). A super El Niño requires that one of two types of El Niño events, where warm sea surface temperatures (SST) concentrate in the Eastern Pacific as opposed to the Central Pacific, aligns with a particular phase of another climate phenomenon known as the Indian Ocean Dipole (IOD), where warm SST concentrate in the western Indian ocean (Pan et al. 2018). These events are termed Eastern Pacific (EP) El Niño and positive-phase IOD, respectively. The individual effect of these events greatly reduces precipitation over the southern half of Borneo, such that when aligned, extraordinary drought conditions plague this region (Pan et al. 2018). The fact that major fires have occurred in KNP only during super El Niño events may reveal a specific precipitation threshold in these forests, below which large-scale fires become possible with nearby ignition sources. This information can help develop or better inform an early warning system specific to KNP that works to intensify fire prevention when these forests become most vulnerable.

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[5] Based on a review of the literature in Table 1 and other sources, including GFW (2019), Rautner et al. (2005), Rijksen & Meijaard (1999), Barber & Schweithelm (2000) and Siegert & Hoffmann (2000). Fires during the 2015/16 El Niño only occurred in the NE and SW regions of KNP (GFW 2019).

1.3. Poaching & Killings

Although my study found no current signs of hunting or poaching activities at the sites visited, my review of the available literature indicates that removals by poaching and conflict-related killings represent a major standalone threat to the orangutan population in the GMA of KNP. In the case of KNP, the threat of poaching can be broken down into [accidental] bycatch, removal for the pet trade and hunting for meat.

At least three cases have been reported in which an orangutan has been injured in KNP by a ground trap/snare typically set for deer or boar. The first of these was reported in the GMA in the mid-1980s (Suzuki 1988), then again in 2010 in the forested interior of KNP (Wisnubrata 2010) and finally near coastal community lands in 2016 which resulted in infection and death for the entrapped orangutan (Aditya 2016). According to P. Kuncoro (pers comm), dozens of traps/snares were also discovered in 2010 in an area of western Bendili that is frequented by resident orangutans.

The poaching of orangutans for the pet trade was considered 'rampant' in KNP in the 1990s when dealers openly traded infants out of nearby cities (Rijksen & Meijaard 1999, p. 229). Reports over the past decade have confirmed that young orangutans continue to be kept and sold as pets by community members that live within KNP (BOSF 2015; Kompas 2008; Fajri 2018; Sumidi 2008). These reports only identify the origin of two of these orangutans, one of which was purchased from a seller who caught the infant in a rubber plantation (Sumidi 2008) while the other was caught from an abandoned coal mine and kept as a pet by a community member (BOSF 2015). By comparison, the only mention I found of orangutans being hunted for meat in KNP is found in Rijksen & Meijaard (1999, p. 229) who described a butcher in the neighboring city of Bontang that regularly sold orangutan meat up until the late 1990s.

Although bycatch and poaching for the pet trade certainly contribute to removals from this population, a review of the literature indicates that conflict killings on (or in relation to) agricultural lands account for most of the human-related orangutan deaths in KNP (see Wibisono 2018; detikNews 2012; Vita 2016; Liputan 2016; Liputan6 2016; Aditya 2016; Wardah 2011). Survey-based research has previously supported this inference in finding that communities in East Kalimantan report the highest rates of human-orangutan conflict relative to other provinces in Kalimantan (Meijaard et al. 2011); some concluded that issue alone could drive all orangutan populations in East Kalimantan to extinction by 2025 (Abram et al. 2015). This conflict has grown alongside the extensive loss of orangutan habitat in this province that has forced orangutans into farmers' gardens and plantations in search of food. Young oil palms in plantations are particularly susceptible to damage from orangutan raids since one orangutan can destroy upwards of 50 oil palm shoots in one bout (Brown & Jacobson 2005).

In the late 1980s, oil-palm plantation managers in East Kalimantan reportedly began offering sizable rewards to community members willing to extirpate orangutans from the surrounding forests in attempt to protect their young oil-palm shoots from destruction (Rijksen & Meijaard 1999, p. 143). Similar reports have recently emerged in an area southwest of KNP where, in 2011, bones from dozens of tortured orangutans were discovered in connection with agricultural conflicts (Wardah 2011). Many of the accounts of human-orangutan conflict in East Kalimantan describe torturous (often fatal) injuries inflicted upon orangutans, including injuries to the teeth and gums, stab wounds to the head (Yamin 2014) and hands (detikNews 2012), the burning alive of an adult female orangutan and her dependent offspring in a garden-fire that was set to entrap and kill them (Liputan 2016), and more recently, the death of an orangutan that suffered 130 gun-shot wounds in addition to numerous stab wounds from a machete and other blunt objects (Wibisono 2018). Numerous orangutans are relocated from community gardens each year, with 10 reported cases of human-orangutan conflict that KNP authorities handled in 2016 (BTNK 2016) and 2 in 2017 (BTNK 2017), but there clearly remains a malignant animus held by many farmers in East Kalimantan toward orangutans that must be examined further to address the serious threat of removals from this population.

1.4. Tourism

The tourism practices I observed in the Prevab area over one ninety-minute period did not comply with best practice guidelines for orangutan tourism (Macfie & Williamson 2010; Williamson & Macfie 2014) and, if left unaddressed, may pose threats to these orangutans for a number of reasons. For one, the number of observers quickly reached eleven individuals for a prolonged period of time, which far exceeds the maximum of six observers (four tourists, two guides) recommended by Williamson & Macfie (2014). Noise level was also not controlled through my observation period, and the guides spent much of the time laughing together away from the group of observers. Group size and noise levels bear restrictions in orangutan tourism because orangutans often experience high stress levels when followed by a large, raucous group of observers, which can suppress reproductive and immunological functions in targeted orangutans (Russon & Wallis 2014; Williamson & Macfie 2014). Despite a surge of tourists between July and August, orangutan tourism in the Prevab area is formally open year-round without suspending practices for the three-month period (per year) recommended by Macfie & Williamson (2010), which may be another source of stress for even habituated residents.

The observing group of tourists, guides and researchers also stayed with the orangutans they found far longer than the maximum limit of one hour (per individual per day) and frequently exceeded the minimum distance (10 m) prescribed for observers not wearing respiratory masks (Williamson & Macfie 2014). Neither were such masks provided to or worn by any visitor. Neither tourists nor researchers were required to provide proof of a recent tuberculosis skin test or vaccinations to observe orangutans. Apart from elevated stress levels in focal orangutans, these factors also heighten the risk of disease transmission from human observers to orangutans (Macfie & Williamson 2010; Williamson & Macfie 2014); this could place the population in the GMA at risk of a disease outbreak. Reported characteristics of the GMA orangutan population such as high rates of nest reuse (Bebko 2018; Niningsih 2017; Rayadin & Saitoh 2009) and habitual travel routes and feeding locations (Bebko 2018) may further heighten the risk of a disease outbreak in this population (Foitova et al. 2009).

1.5. Surrounding Activities

Many of the degradative human activities taking place to the north and east of the GMA threaten the long-term viability of the area's orangutan population, some of which (ignition sources, garden expansion) have been discussed in other sections of this report. Most notably, industrial mining by KPC is currently expanding closer to the northern border of the GMA at a rapid rate, gradually isolating the orangutan population in the GMA from the small but important orangutan population (est. 51 individuals) in the fragmented network of reclamation habitats managed by KPC, the closest unit of which is less than 3 km from the GMA (Niningsih 2017; Mukhlisi et al. 2015; Mukhlisi & Gunawan 2019).

CONCLUSION

Similar to the many other wild populations of *P. pygmaeus* sp. that survive throughout Borneo, the orangutan population of the Greater Mentoko Area in Kutai National Park persists in a region of ever-changing habitat conditions and threat dynamics that increasingly challenge its long-term viability. Numerous degradative activities surrounding this region of KNP - including industrial mining to the north, illegal clear-cutting to the south and agricultural expansion along the immediate riverine boundary - continue to isolate the resident orangutan population from other units within and outside KNP, while illegal logging and an abundance of ignition sources in and around this protected area have increased the potential for cataclysmic-scale fires in these forests in the event of another super El Niño drought. Despite the remarkable resilience displayed by this population through extensive habitat damage including two major fire events in the past, this report highlights the current threats and substantial changes in the forested habitats and anthropogenic activities in the GMA of KNP over the last twenty years that may compromise the ability of this population to survive another major degradative event. Conservation efforts within the GMA or KNP as a whole should address obstacles before the KNP authority to enforce Park rules (e.g., aversion to Park rules and air of lawlessness in Park communities), ignition sources surrounding the GMA, particularly during severe droughts, and factors driving community members to acquire or expand existing agricultural lands (e.g., purchase of smallholder crops by industrial mills to increase throughput). The main implications of this report are its contribution of information to future research and conservation initiatives with this population and to that which is required by researchers to run population and habitat viability assessments for *Pongo pygmaeus morio*.

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APPENDIX A

Table 1. Reports of habitat conditions[1] and/or human activities in the Mentoko (M) and Prevab (P) area(s).

Researcher(s)	Study Period	Location
P. Rodman	70-71, 75, 77, 79	M
J. Kurland	71	M
C. & W. Wilson	72	P
M. & D. Leighton	77-79, 83-84	M
J. Mitani	81-83	M
L. Berenstain	82	M
J. Cant	82	M
A. Suzuki	83-84, 85-86	M+P
A. Susilo & J. Tangketasik	85-86, 87	M+P
J.L. Campbell	85-86	M
Y. Rayadin	06-07	P
Y. Santosa & Krisdijantoro	07	M+P
S. Jinarto & C. Boer	07-08	P
A. Setiawan	08	M+P
L. Niningsih	09, 13-14	P
A. Russon	10-present	M* (2010-2019) & P (Est. 2015-2019)
A. Bebko	10-12	M*
A. Ferisa	12	M*+P

[1] Analysis/description of forest structure, tree & liana species composition, food availability or forest degradation
NOTE: Horizontal line separates studies conducted before 97/98 fires (top half) with those conducted after (bottom half).
* Bendili study area