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Shrimp farms, fire or palm oil? Changing causes of proboscis monkey habitat loss

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ABSTRACT

Proboscis monkeys, endemic to Borneo, inhabit the fastest-disappearing forest types within the island. Previous studies described multiple causes of their habitat loss, with aquaculture and logging figuring among the major threats. In Balikpapan Bay, which hosts one of the largest populations of the species, a previous Population Viability Analysis identified wildfires as the biggest threat. In this study, we analysed proboscis monkey habitat loss in Balikpapan Bay from 2000 to 2017 by combining satellite images with information on the specific causes of habitat loss available from regular monthly monitoring. We did not identify wildfires and aquaculture as the most prominent causes of recent habitat change. Instead, our data highlighted the recent negative impact caused by the development of industry and infrastructure. Palm oil production caused habitat loss throughout the period, but it advanced from plantations development to the development of the processing industry. The rate of habitat loss is slower compared to all previous estimates, and slowed down even further following increased conservation efforts after 2007. However, it is most detrimental to the non-mangrove habitat, which may provide proboscis monkeys with key food resources. The rate of mangrove loss may therefore be a poor indicator of the future prospects of the population.

1. Introduction

Indonesia's forests have declined dramatically due to a sequence of unsustainable logging practices, forest fires, smallholder agriculture and large-scale plantation development (Austin et al., 2019, 2017; Curran et al., 2004; Fuller et al., 2004; Gaveau et al., 2018; Tsujino et al., 2016), resulting in the rapid shrinking of the area of habitat available to wildlife

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species. Proboscis monkeys (*Nasalis larvatus*), an endangered primate endemic to Borneo, is one of many species impacted by this habitat loss. For reasons we do not yet fully understand, they typically inhabit forests near open water, such as mangrove or riverine forests (Kawabe and Mano, 1972; Salter et al., 1985; Sha et al., 2008). This is possibly related to the deficit of minerals, such as phosphorus, in the inland forest (Matsuda et al., 2013). Mangrove and riverine forest has become one of the most threatened habitats of Borneo, suffering both from human activities (Langner et al., 2007; Meijaard and Nijman, 2000a) and from natural catastrophes (Yeager and Fredriksson, 1998).

Balikpapan Bay (East Kalimantan, Indonesia) hosts one of the largest populations of proboscis monkeys. It was originally estimated to contain 100-1000 individuals (Meijaard and Nijman, 2000a), yet subsequently this estimate changed to 1400 individuals after the first detailed survey in 2007 (Stark et al., 2012), and the latest survey suggests an even larger population size (Toulec, unpubl. data).

Stark et al.'s (2012) attempted to model the future development of the Balikpapan Bay proboscis monkey population. The baseline scenario of this model predicted a rapid population decline with a non-zero risk of extinction. The predicted population decline is not due to hunting, which is considered to be a negligible threat in Balikpapan Bay, although it poses serious threats elsewhere (in Sarawak, populations may have declined by 50% due to hunting) (Bennett and Gombek, 1993). The decisive factor behind the predicted decline was habitat loss, notably due to the wildfires occurring in conjunction with the El Niño-Southern Oscillation (ENSO) events. Therefore, eliminating the forest fires was recommended by Stark et al. (2012) as the most promising population management strategy for the Balikpapan Bay population. Unfortunately, during the 2015 ENSO event, which affected the majority of Southeast Asia, Balikpapan Bay experienced several major forest fires that destroyed a significant portion of primate habitat both within and outside Sungai Wain Protection Forest (Pro Natura Foundation, 2016). The impact of the fire on the proboscis monkey habitat can now be assessed based on the empirical data.

Meijaard and Nijman (2000a) identified several other causes of proboscis monkey habitat loss in Kalimantan (Indonesian part of Borneo), besides the forest fires, including logging, shrimp farming (aquaculture), swamp reclamation, and gold-mining. The leading cause of a well-documented proboscis monkey population collapse in Pulau Kaget Nature Reserve was agricultural expansion (Meijaard and Nijman, 2000b). For the Malaysian state of Sabah, Sha et al. (2008) identified agriculture, aquaculture, fire, logging, and human habitation as the leading causes of proboscis monkey habitat loss and fragmentation. For the other Malaysian state, Sarawak (Bennett, 1988), lists logging, silvicultural treatment post logging (poisoning non-timber trees), agriculture, exploitation of mangroves for woodchip and cordwood, and aquaculture as the major threats (forest fires are not listed). The reported differences most likely reflect not only the differences in land use among the political divisions of Borneo but also from overall changes of land use within the two-decade period covered by these studies.

With increasing conservation efforts, which include intensive field investigations and monitoring, the data on causes of primate habitat loss has become more detailed than ever before. Rather than just listing the threats, we can quantify their exact contribution to the habitat loss, and the patterns of change over the time. The aim of this study is to provide detailed data on the extent and causes of proboscis monkey habitat changes in the single well-studied field site of Balikpapan Bay, over the period of 17 years (2000–2017), which includes the 2015 ENSO event that caused several forest fires within the Balikpapan Bay watershed area. Thanks to the detailed monitoring program by a group of local fishermen that has been ongoing since 2008 under the supervision of one of the authors (SL), we can identify the causes of habitat loss to a greater extent than in any of the previous studies. The results enable us to assess the effect of the threats that have been recognised in the past and highlight new emerging threats that can affect proboscis monkeys and other species sharing the same coastal habitat in Borneo.

2. Methods

2.1. Study area

Balikpapan Bay is located on the coast of Kalimantan, the Indonesian part of Borneo Island (1° 8′ S, 116° 45' E). Administratively it belongs to the province of East Kalimantan. The coast of Balikpapan Bay is divided between two districts. The smaller south-east part of the coast belongs to the Balikpapan City, while the majority of Balikpapan Bay is located within Penajam Paser Utara (PPU) Regency. The coast of Balikpapan Bay does not belong to any protected area, although one of its upper watershed areas is protected at the provincial level as Sungai Wain Protection Forest (Hutan Lindung Sungai Wain; Fig. 1).

The coastal mangrove forests can be found along 54 river systems of Balikpapan Bay. Most of the rivers within Balikpapan Bay are small and strongly tidal, only several larger streams are brackish or freshwater in their upper reaches. Therefore, the extent of alluvial and freshwater swamp forest is rather negligible compared to the extensive mangrove forest area.

2.2. Proboscis monkey habitat definition

The extent of the proboscis monkey habitat was determined from satellite images, with additional information obtained during regular monthly field surveys by SL and his team over the course of several years. We divided the proboscis monkey habitat in Balikpapan Bay into two highly distinct categories - mangrove forest and non-mangrove forest. The mangrove forest is an unmistakable plant community (consisting mainly from *Sonneratia* spp., *Avicennia* spp., *Bruguiera* spp., *Nypa fruticans*, and the most dominant *Rhizophora* spp.), and its extent is clearly determined by the influence of tidal water. Small

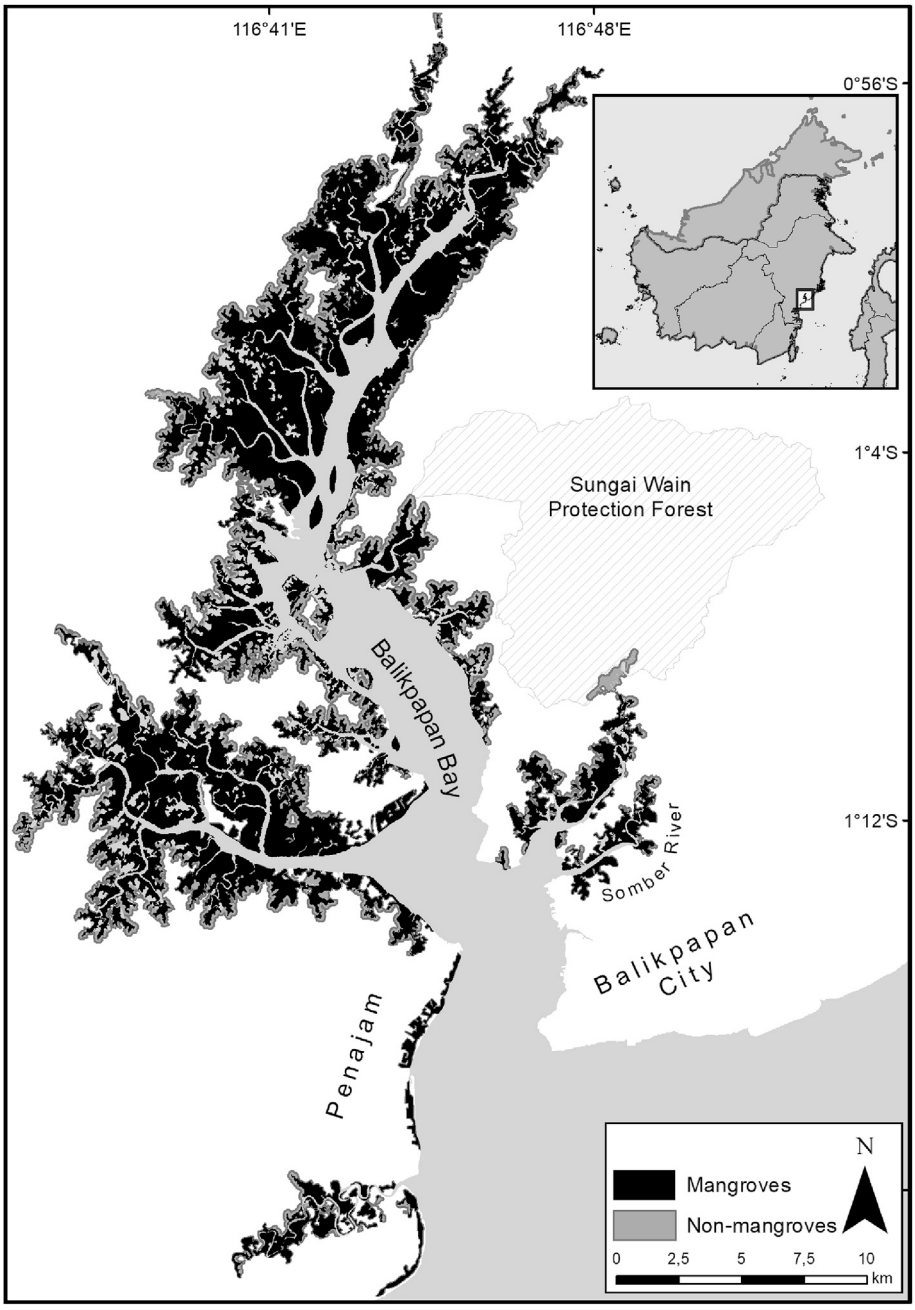

Fig. 1. Balikpapan Bay and extent of proboscis monkey habitat, represented by two forest types: mangroves and non-mangroves.

patches of alluvial riverine and freshwater swamp forest with no tidal influence (as identified during field surveys) have been excluded from mangroves and classified as one of the non-mangrove habitats. All mangrove forest adjoining the bay was considered proboscis monkey habitat, although the population may have already been extinct in some of the isolated mangrove patches (identification and exclusion of these empty patches would be unlikely to change the overall results).

Defining the non-mangrove habitat is more difficult. The proboscis monkeys in Balikpapan Bay have been observed in all types of vegetation behind the edge of mangroves with a continuous tree cover. However, an additional requirement to classify the non-mangrove forest as proboscis monkey habitat was proximity to water. In contrast to several previous authors (Bennett and Sebastian, 1988; Boonratana, 2000; Matsuda et al., 2009; Salter et al., 1985; Table A1) we defined non-mangrove habitat by its distance from the inland edge of the tidal mangrove swamp. This decision is based upon regular observations of proboscis monkeys using this edge habitat even if it is located several hundred meters from the nearest riverbank (SL, pers.

obs.). We decided to use a conservative distance of 120 m inland from the landward edge of the tidal mangrove swamp. This is based on our field experience in Balikpapan Bay. It represents the maximum distance from the edge of mangrove forest, where we observed proboscis monkey from 2006 to 2019. Non-forest vegetation cover within this belt was not considered proboscis monkey habitat.

2.3. Satellite images analysis

Using USGS Global Visualization Viewer (GloVis), we looked for multispectral satellite images of Balikpapan Bay (Path 116 and 117, Row 61) with excellent visibility. We predominantly analysed images with <10% of cloud cover, yet we often had to use multiple images to obtain a complete picture of the bay with good visibility. We used the satellite Landsat 5 (sensor TM) from 2000 to 2011 and Landsat 8 (sensor OLI) from 2013 to 2017 to obtain suitable images.

We analysed the acquired images in the software ArcGIS 10.6, pan-sharpened them to improve resolution (to pixel size of 15 m) and afterwards created a mangrove mask. The mask was based on the clearly distinctive colour of mangrove forests, directly visible on the satellite images.

Mangroves are naturally dark greenish in colour, compared to adjoining secondary forests (light green) or shrimp/fish farms (dark grey or brown) placed within mangroves. The potential extent of non-mangrove habitat was added by creating a buffer zone of 120 m around mangroves, from which all non-forest vegetation was manually erased based on visual inspection of colour differences (using Colour Infrared and False Colour band combinations). This allowed us to assess the extent of proboscis monkey habitat in 2000 and subsequently detect all habitat changes in 2007 and 2017.

Assuming a constant rate of habitat loss in each of the 2 periods (2000–2007, and 2008–2017), we have used the following formula (FAO, 1995) to calculate the annual rate of habitat loss (q). Where A_2 represents initial habitat size, A_1 final habitat and "n" the number of years:

$$q = \left(\frac{A_2}{A_1}\right)^{1/n} - 1$$

Regeneration was calculated for the whole period, from 2000 to 2017. Since regeneration is a slow process, which cannot be easily determined on a year-by-year basis from satellite images (notably the initial stages of regeneration), we calculated the yearly percentage of regenerated habitat using the available data for 2000 and 2017. We defined regeneration as an area, which was not defined as proboscis monkey habitat before 2000, that became habitat by 2017. In all cases, we were able to confirm through the combination of satellite imagery inspection, direct observation of the area and communication with local residents, that this was a forest destroyed by previous human activities.

2.4. Causes of habitat loss

We used a long-term database collected by a team of local fishermen that has patrolled and monitored the area on a monthly basis since 2008. This program, which started under initial coordination by SL, was subsequently formalised as POKWASMAS (Kelompok Pengawas Masyarakat) based on the initiative of the Ministry of Fishery and Marine Affairs (Keputusan Menteri Kelautan dan Perikanan No. 58/2001, Tata Cara Pelaksanaan Sistem Pengawasan Masyarakat dalam Pengelolaan dan Pemanfaatan Sumber Daya Kelautan dan Perikanan). The surveillance takes a multi-faceted approach, including receiving immediate reports from a network of local informants (fishermen), and regular monthly patrols along the coast by boat and on foot. The monthly reports are shared with government officials as well as with NGOs and researchers. POKWASMAS, however, monitors less than half of the total proboscis monkey habitat. The ground information on habitat changes in the remaining sections was based on opportunistic field observations by TT and SL in May and June 2017. We also used GoogleEarth 7.3 software, which shows very detailed satellite images from which the cause of habitat change can often be directly observed.

3. Results

The majority of proboscis monkey habitat in Balikpapan Bay in 2000 was represented by 168.00 km^2 of mangroves (72.50% of the total habitat), completed with 63.71 km^2 of non-mangroves. The total extent of habitat decreased from 231.71 km^2 in 2000 to 215.87 km^2 in 2007, and to 203.01 km^2 in 2017, the annual rate of habitat loss being 0.93%. The absolute rate of habitat loss (1.99 km^2/yr) was almost 7 times faster than the rate of habitat regeneration (0.30 km^2/yr), resulting in a net annual loss of 0.78% of proboscis monkey habitat over the period of 17 years (Fig. 2). When we divided the whole time period into two (before and after the initiation of the proboscis monkey conservation efforts by SL in 2007), we observed faster habitat loss in the first period, 2000–2007, (2.26 km^2/yr, 1.02%/yr.) than in 2008–2017 (1.29 km^2/yr, 0.62%/yr.).

Non-mangrove forests suffered a considerably higher loss of 1.05 km^2/yr (1.94%/yr.), compared to the loss of 0.64 km^2/yr (0.40%/yr.) for mangroves. Mangroves also regenerated faster, by 0.20 km^2/yr, than non-mangroves with 0.09 km^2/yr. This difference was most evident before 2007 but remains pronounced even after 2007 (Fig. 3).

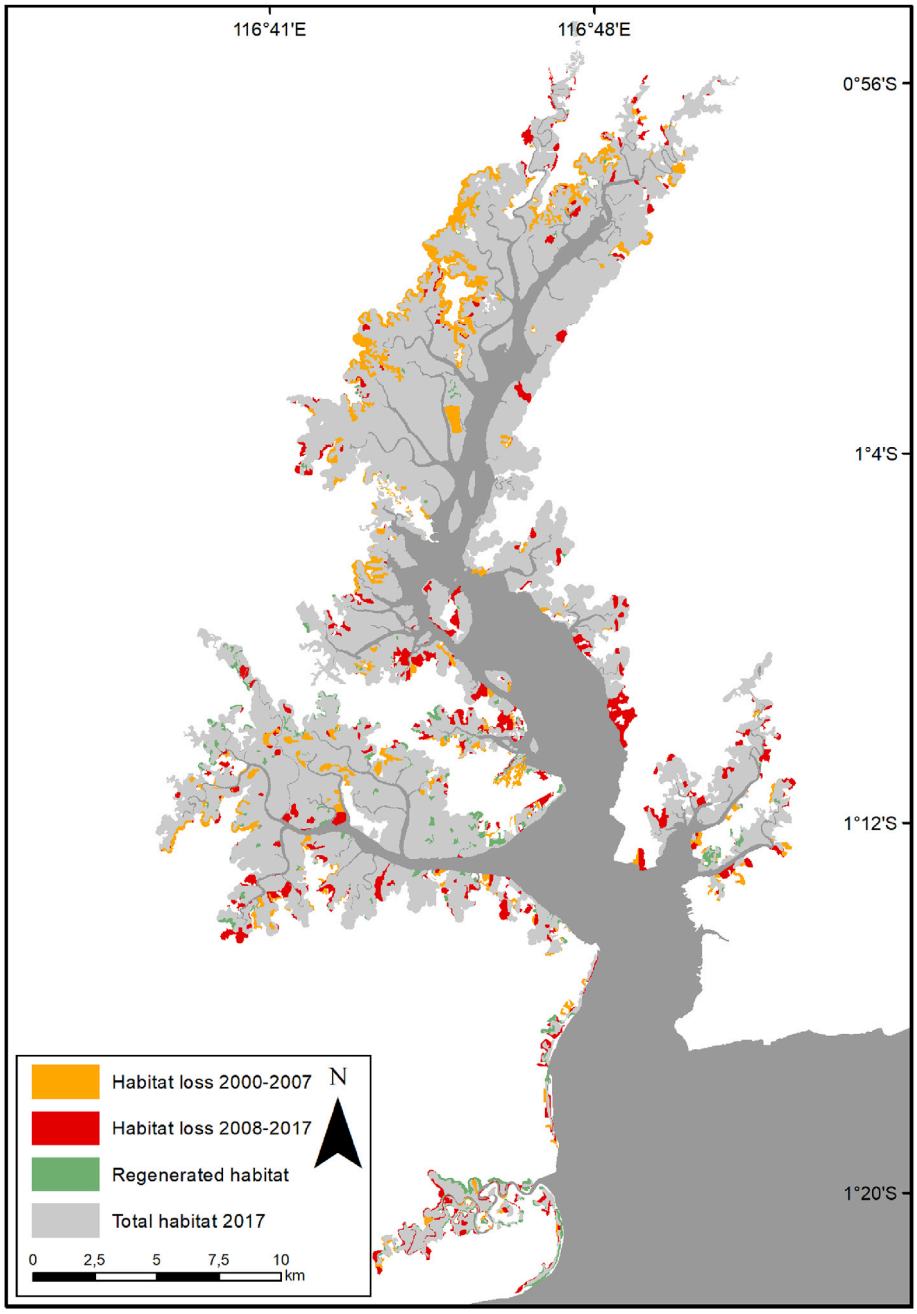

Fig. 2. Changes in the habitat of proboscis monkey in Balikpapan Bay between 2000 and 2017.

3.1. Causes of habitat loss

Using the data provided to us by the local surveillance team, we were able to associate every fragment of lost habitat with a likely cause. Oil palm plantations were by far the most prominent cause of habitat loss in Balikpapan Bay within the monitored period, followed by aquaculture, industrial development, and coal mines and terminals (Table 1).

The two different habitat types declined due to different causes. Aquaculture was the major cause of mangrove loss, whereas the deliberate burning of forests and growing crops was negligible due to the swampy mangrove profile. More than half of all non-mangrove forests' losses were caused by oil palm plantations that were created mostly on dry land. On the contrary, aquaculture was rarely developed in non-mangrove forests. Coal mines, terminals, and industrial development were located in both types of habitat.

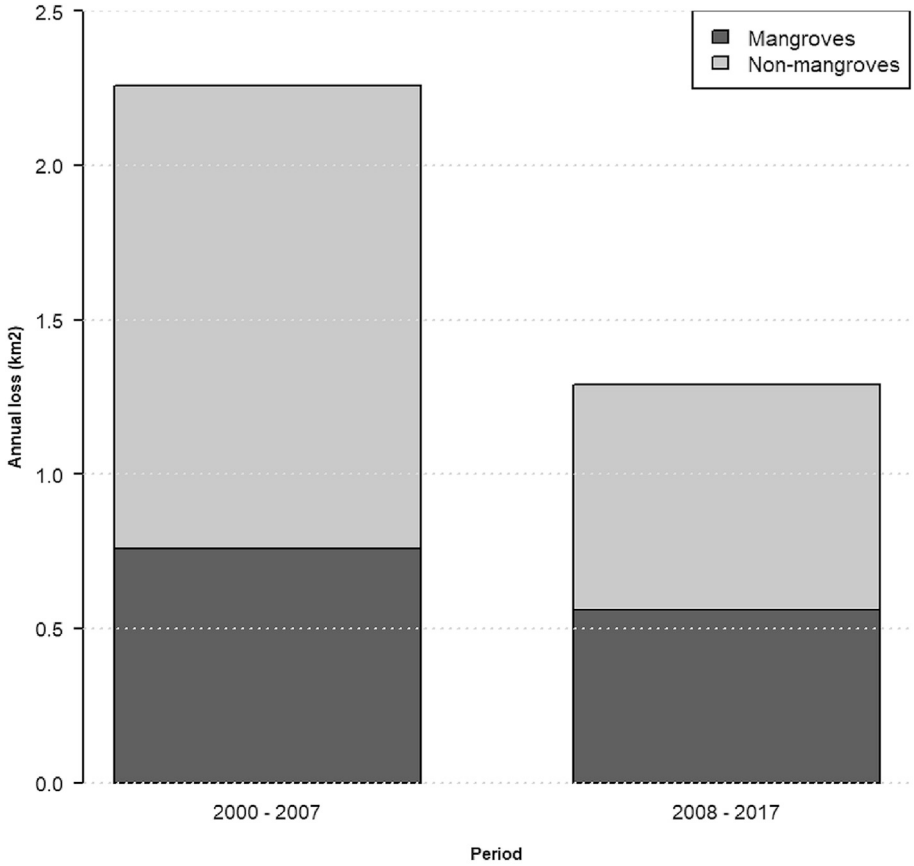

Fig. 3. Annual habitat loss in Balikpapan Bay in two distinctive periods, with emphasis on different types of habitat.

Comparing the causes of habitat loss before and after 2007, only the impact of aquaculture and palm oil plantations decreased greatly in the second period; as was the case with rubber plantations, however this was on a smaller scale. Reverse development was observed in cases of building roads, growing other crops, and the most destructive cause of habitat loss after 2007, industry (Fig. 4 & Fig. 5).

4. Discussion

The rate of proboscis monkey habitat loss in Balikpapan Bay was rather slow compared to the predicted habitat loss applied in the baseline scenario of the PVA by Stark et al. (2012). These authors based their analysis on the mangrove deforestation rate published by Langner et al. (2007), cutting this estimate by half (to 4%/yr.) for recognizing that Langner et al.'s study focused on the period of the most intensive conversion of mangroves into shrimp farms in Borneo, which subsequently slowed down. The mangrove loss in Balikpapan Bay between 2000 and 2017 (0.40%/yr.) was slower compared to the entirety of Indonesia (1.72%/yr.) or overall Southeast Asia (2.12%/yr.) (Richards and Friess, 2016). The loss of non-mangrove habitat was faster compared to the loss of mangroves; nevertheless, the total loss of the proboscis monkey habitat between 2007 and 2017, i.e. 0.93%/yr. is still below any of the above-cited estimates.

The finding that the non-mangrove part of the habitat in Balikpapan Bay is being lost at a disproportionately high rate (i. e., 1.94%/yr.), is however disturbing. The mangroves of Balikpapan Bay are largely dominated by *Rhizophora apiculata*. Their vegetation composition differs from habitats studied recently by other authors, who have demonstrated presence of important proboscis monkey food resources in the mangrove forest (*Sonneratia casaeolaris*, Matsuda et al., 2019; *Bruguiera gymnorrhiza*, Bernard et al., 2019). If the proboscis monkeys that inhabit these *Rhizophora*-dominated mangroves find their key food resources in the surrounding terrestrial non-mangrove forests, then the disproportionately high loss of these forests impacts the overall chances of survival for the proboscis monkeys. The availability and nutritional quality of food resources in *Rhizophora*-dominated mangrove and non-mangrove forest are subject to current research (Koubek & Lhota, in prep.).

In one of the locations, which is a highly degraded non-mangrove part of the habitat (Somber River, directly adjoining Balikpapan City), we have observed an increased mortality of the mangrove tree *Sonneratia alba* from 2007 until now (Plate A 1). While localized mortality of these pioneer trees seems to be a natural phenomenon, which has already been reported

Table 1
Causes of habitat loss in Balikpapan Bay (2000–2017) with emphasis on two distinctive forest types and period of deforestation.

Cause	Mangrove loss (km^2)	Mangrove loss (%)	Non-mangrove loss (km^2)	Non-mangrove loss (%)	Before 2007 (km^2)	After 2007 (km^2)
Aquaculture	5.57	44.92	0.11	0.56	3.83	1.86
Deliberate burning	0.04	0.35	1.11	5.23	0.63	0.52
Coal mines and terminals	2.32	18.71	2.30	10.79	1.91	2.71
Coconut plantations	0.15	1.27	0.00	0.00	0.10	0.05
Housing development	0.42	3.40	0.33	1.59	0.20	0.55
Industrial development	3.17	25.55	2.46	11.57	0.92	4.72
Oil palm plantations	0.00	0.00	12.01	56.29	10.28	1.73
Other crops	0.06	0.51	0.77	3.61	0.12	0.70
Rice fields	0.07	0.61	0.01	0.08	0.00	0.09
Road development	0.52	4.25	0.82	3.86	0.18	1.16
Rubber plantations	0.05	0.43	1.37	6.42	1.15	0.26
Total	12.41	100.00	21.34	100.00	19.36	14.39

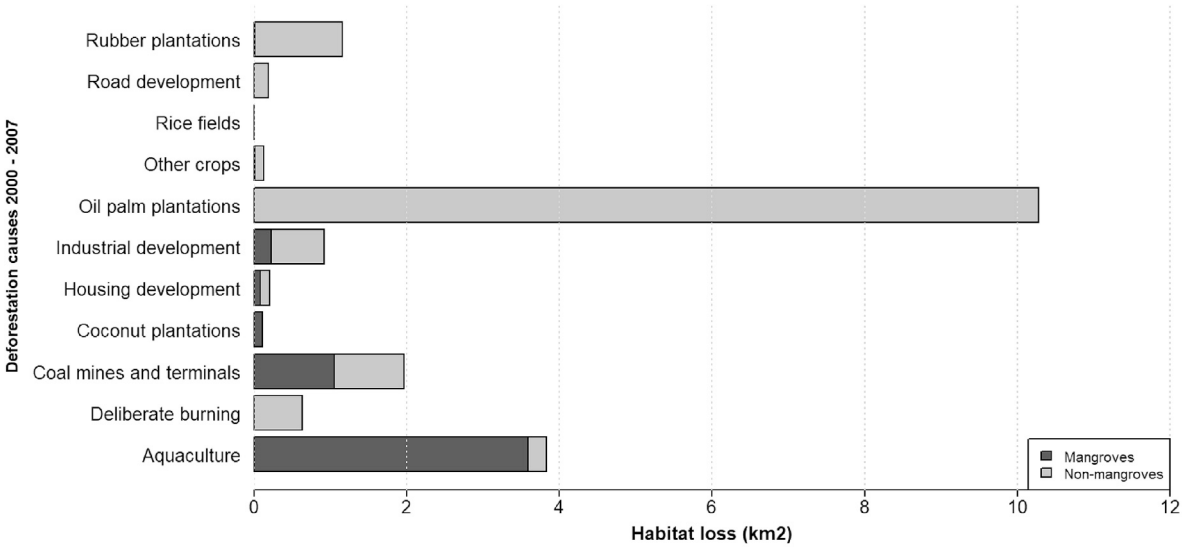

Fig. 4. Various habitat loss causes in Balikpapan Bay period 2000–2007, also comparing two forest types representing proboscis monkey habitat.

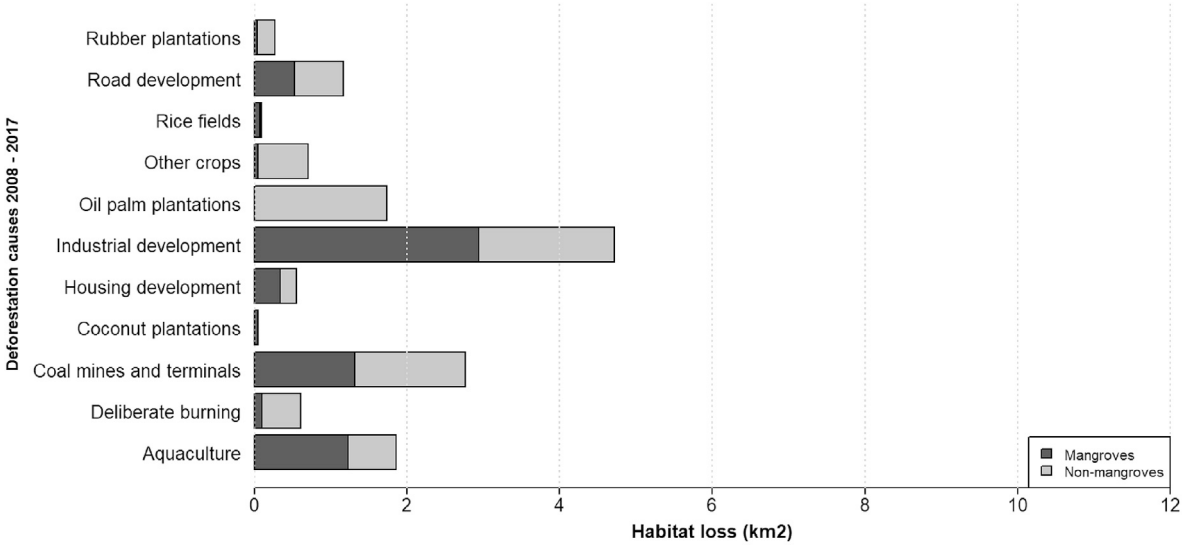

Fig. 5. Various habitat loss causes in Balikpapan Bay period 2008–2017, also comparing two forest types representing proboscis monkey habitat.

(Kern, 1964) for mangroves of Brunei, the situation on Somber River seems to be rather alarming. *Sonneratia alba* represents the single main food resource for the monkeys living in this highly fragmented habitat, and the current observed tree mortality is clearly a result of proboscis monkeys repeatedly, often daily, foraging on the young shoots. The current situation in Somber River closely resembles the scenario already witnessed in Pulau Kaget Nature Reserve, where the proboscis monkey population collapsed as a result of the expansion of illegal agriculture and the subsequently increased mortality of *Sonneratia caseolaris* trees (Meijaard and Nijman, 2000b). This suggests that the total extent of mangrove habitat and the rate of mangrove loss may be a rather poor measure of the carrying capacity of the habitat for the proboscis monkey population. Instead of the total habitat, the availability and access to key food resources may determine the future development of the population.

Similar to most previous studies (Bennett, 1988; Meijaard and Nijman, 2000a; Sha et al., 2008) we have identified multiple causes of proboscis monkey habitat loss. As economic development progressed, these causes shifted from smallholder aquaculture to large-scale plantations and then to industry.

4.1. Aquaculture

Aquaculture (shrimp and milkfish farming) is the main driver of mangrove loss worldwide (Hamilton, 2013; Valiela et al., 2001) and it is being considered one of the biggest threats to proboscis monkeys (Bennett, 1988; Meijaard and Nijman, 2000a; Sha et al., 2008) as well. Our data, however, does not identify aquaculture as the current major threat in Balikpapan Bay.

In most of Balikpapan Bay, the rate of mangrove loss decreased considerably after 2007, leaving large areas of intact mangrove habitat. This is partly due to intensive conservation efforts by a team of local fishermen that patrols along the coast of Balikpapan Bay almost every month. All illegal human activities are reported to the local governments and other stakeholders, including the leader of the indigenous Pasir community and local media. As a result, small investors are hesitant to establish new farms, which are illegal under current regulations. The second, and probably more important reason for the decline of the mangrove conversion into aquaculture, is the fact that several pond owners went bankrupt in the recent past. Based on the personal communication with the pond owners, it was due to the introduction of the White Spot Syndrome Virus, which causes high mortalities of crustaceans (reaching up to 100%), transmits swiftly (Stentiford et al., 2009) and often forces the owner to shut down whole farm. The owners furthermore mentioned a combination of water pollution and increased acidity due to coal mining and industrial development along the coast, unsuitability of locally available material for building proper dikes, and costly maintenance of the dikes (due to the putative increase in water level caused by land subsidence, possibly influenced by oil and underground water extraction).

While the overall rate of mangrove conversion in aquaculture keeps slowly decreasing after the biggest endeavour of the 1980s (Richards and Friess, 2016), the current situation in Balikpapan Bay should not be generalized to other locations. Shrimp and milkfish farming remain a major threat in areas of shallow bays and river deltas, where aquaculture continues to be developed profitably (Malik et al., 2017). In the Mahakam River delta, for example, roughly 210 km^2 of mangroves were turned into shrimp ponds between 2000 and 2010 (Rahman et al., 2013).

In Balikpapan Bay, many of the abandoned ponds have been left unattended, and these patches regrow naturally with healthy mangroves that are again being used by the proboscis monkeys. Mangrove planting, often in form of ceremonial events, is a prominent part of green propaganda by the local government (Lhota et al., 2019), but as described in other sites, it is usually unsuccessful due to the practice of planting improper species in improper sites (Harkes et al., 2015; Oh et al., 2017). There are patches of mangroves in Balikpapan Bay that result from the mangrove planting events; however, their size is too small, and on the scale of analysing the satellite images, they are virtually immeasurable.

4.2. Industry & infrastructure development

Industrial expansion, which was not previously listed among the major threats to proboscis monkey habitat (Bennett, 1988; Meijaard and Nijman, 2000a; Sha et al., 2008), became the chief driver of mangrove loss in Balikpapan Bay after 2007. Balikpapan Bay can be accessed by large oceanic ships, which makes this area particularly prone to industrial development. Abandoned shrimp farms, including regenerated mangroves that are already being used by proboscis monkeys, represent one of the frontiers of industrial expansion. This is due to their unclear land status, which may or may not be considered mangrove forest, making it easier to violate regulations that protect the mangrove forest (Lhota et al., 2019).

Land speculations alone, are already causing habitat loss. Some of the unproductive shrimp farms are even maintained as functional in hopes of selling the land to a corporation (based on the personal communications with the pond owners). Additional areas of mangroves have been clear felled for the alleged purpose of building a pond, which ends up never happening; instead, some of these proposed ponds are sold to a corporation for the purpose of industrial development. In analogy, most of the non-mangrove deforestation described as intentional burning can be linked to land speculations. Farmers felled and burnt the trees, allegedly for the purpose of cultivation. The land was however not planted with crops. Instead, the farmer then tries to sell the land to a corporation, successfully or not.

The industrial expansion in Balikpapan Bay, notably after 2007, impacted both components of the proboscis monkey habitat, mangroves as well as non-mangroves. The situation was made critical by the 2015–2032 spatial plan of Balikpapan City, which has already been approved by the local government (Peraturan Daerah Kota Balikpapan No. 12/2012, Rencana Tata Ruang Wilayah Kota Balikpapan Tahun, 2012–2032). This spatial plan projects large scale conversion of coastal forests as an

extension of the Kariangau Industrial Area (KIK). Similarly, a large area of proboscis monkey habitat in the neighbouring district of Penajam Paser Utara has been classified as the Buluminung Industrial Area (KIB) in the district-level spatial plan. According to the new spatial plan, all mangrove forests within the KIK area should remain intact, while the non-mangrove forest has been allocated to industry. Nevertheless, both mangrove and non-mangrove forest within this area are being converted to industry.

A decree of the Penajam Paser Utara district government (Peraturan Daerah Kaabupaten Penajam Paser Utara No. 24/2012, Pengelolaan Hutan Mangrove) allows corporations to convert mangroves for other uses, provided that every hectare of deforested mangrove is compensated by replanting mangroves elsewhere, such as on the abandoned shrimp farms. However, while the conversion of mangroves for industrial use is evident, the finding that there is no measurable mangrove restoration due to replanting shows that most of the replanting attempts are either unsuccessful or do not take place at all.

Industrial development is closely linked to the expansion of infrastructure, such as ports, electric lines, and, in particular, roads. The direct impact of road construction in Balikpapan Bay represents only a minor proportion of the total proboscis monkey habitat loss (4.00%). However, it is the indirect impact of road development which is of major concern (Clements et al., 2014). The majority of deforested locations in Malaysia and Indonesia lie within a 2.5 km belt from roads (Hughes, 2018), and building a new road also encourages local people to further deforest the area (Patarasuk, 2013). In Balikpapan Bay, the projected construction of a road across Balang Island, which would effectively split the habitat and start uncontrolled industrial expansion, caused a major public outcry (Hance, 2019). Unfortunately, the road is now under construction.

Compared to some other threats, such as plantation development, industrial expansion tends to cause widely scattered deforestation. Therefore, besides the total loss of the habitat, it is also causing fragmentation of the remaining proboscis monkey population. The population is already divided into several sub-populations, as some sections of habitat are already split by more than 1 km of unsuitable area. The proboscis monkey average daily range varies from 350 to 800 m, while the maximum daily distances travelled ranged from 1550 to 2000 m (Bennett and Sebastian, 1988; Boonratana, 2000; Matsuda et al., 2009; Salter et al., 1985). Currently, the biggest gap between suitable areas of habitat in Balikpapan Bay is 4.2 km (located within the KIK area). This gap can probably be crossed by solitary males (Boonratana, 2000; Kern, 1964), though it is highly unlikely in the case of whole groups and virtually impossible on a daily basis. We can still consider the Balikpapan Bay proboscis monkey population to be a single population with likely genetic exchange between any of the subpopulations. This situation is however likely to gradually worsen as the industrial development proceeds.

4.3. Palm oil plantations, bulking stations, and refineries

Although there are currently multiple industries present within the proboscis monkey habitat in Balikpapan Bay, including chip mills, cement manufacturing, energy (power plants), paint production, and shipping constructions (Tarigan et al., 2017), the most dominant industry is represented by several palm oil bulking stations, refineries, and biodiesel plants, that are currently operating or under construction. The boom of the palm oil processing industry follows the expansion of palm oil plantations that we observed a decade ago. Palm oil plantations are the single most prominent cause of the loss of proboscis monkey habitat in Balikpapan Bay (35.60%), affecting primarily the non-mangroves. While the rate of habitat loss due to plantation development slowed down substantially after 2007, palm oil production remains the leading cause of the proboscis monkeys habitat loss in Balikpapan Bay due to the newly growing processing industry that is affecting both mangrove and non-mangrove forest.

The finding that the conversion of proboscis monkey habitat into palm oil plantations in Balikpapan Bay slowed down after 2007 corresponds with the overall decline of the forest conversion to large-scale palm oil plantations on Borneo, following the peak in 2009 (Austin et al., 2019; Gaveau et al., 2018). This considerable decrease in Balikpapan Bay is clearly related to the status of the land. Most of the land classified as available for agricultural development (kawasan budidaya non-kehutanan) has been converted to plantations not long after 2007. The major remaining area that would be suitable for planting oil palms is the north-east coast, which is however classified as a forestry concession. It is forbidden by Indonesian law (UU No. 18/2013, Pencegahan dan Pemberantasan Perusakan Hutan, Pasal 17; UU No. 41/1999, Kehutanan, Pasal 50), to convert forestry land into agriculture, including oil palm plantations, without permit from the Minister of Environment and Forestry.

In theory, palm oil plantations should not cause a major loss of the proboscis monkey habitat, as it is illegal in Indonesia to deforest protective bands of natural vegetation along the coast and riversides (Kepres No. 32/1990 “Pengelolaan Kawasan Lindung”; Permen PU No. 63/1993 “Garis Sempadan Sungai, Daerah Manfaat Sungai, Daerah Penguasaan Sungai dan Bekas Sungai”). Unfortunately, these regulations are not properly enforced by the local governments. In practise, most of the non-mangrove forest that belongs to the palm oil concessions tends to be deforested, leaving only the mangrove forest untouched, where palms cannot be planted. There were even a few attempts to drain the mangrove swamp in Balikpapan Bay to convert it into palm oil plantations, but these attempts immediately failed. This parallels the cases of allocation of flooded forests for oil palm cultivation in Lower Kinabatangan floodplain, which results in largely unproductive plantations (Matsuda et al., 2018).

Most of the corporations responsible for the loss of the proboscis monkey habitat in Balikpapan Bay are members of the Roundtable on Sustainable Palm Oil (RSPO). It does not seem that the membership in RSPO plays a major role in halting the forest loss in either plantation or industrial concessions. All of the concessions managed by RSPO members violated the RSPO Principles and Criteria by continued conversion of proboscis monkey habitat even after 2005. According to the Principles and Criteria, all proboscis monkey habitat should be classified as a High Conservation Value Forest, more specifically as HCV 1, due

to the presence of rare, threatened or endangered species (RSPO, 2018). In 2013, a complaint against one of the corporations, PT WINA (Wilmar Group) was filled in the RSPO Complaint System (RSPO, 2013). RSPO dealt with the complaint for two years but the case was eventually closed in 2015 without enforcing any improvement.

Some of the proboscis monkey habitat that has been recently destroyed by the RSPO members could be restored. It mostly applies to PT AIEK-Goodhope Asia Holdings Ltd. as the most prominent single stakeholder responsible for proboscis monkey habitat loss in Balikpapan Bay (Fig. A1). This single corporation converted 8.96 km^2 of the non-mangrove proboscis monkey habitat into plantations. If the corporation decides, either voluntarily or under pressure by RSPO, to restore this habitat, they would instantly turn from a major destroyer to a pioneer in proboscis monkey conservation in Balikpapan Bay.

4.4. Forestry plantations

While the main reason for saving the remaining proboscis monkey habitat along the northeast coast of Balikpapan Bay from conversion into oil palm plantations is the status of the land as a forestry concession by PT INHUTANI, this land is currently under threat, too. The corporation has recently started converting forests within its concession into monoculture plantations of *Calliandra*, and possibly rubber. So far, the proboscis monkey habitat remains unaffected by this conversion.

Additional rubber plantations, managed by small farmers, were responsible for only a minor loss of 1.42 km^2 of proboscis monkey habitat in Balikpapan Bay. Proboscis monkeys have been reportedly using rubber plantations in South Kalimantan (Soendjoto et al., 2005). These plantations are managed by smallholders and they represent a landscape of small plantations of various ages, without intensive maintenance, without melioration, and with high representation of “weed” woody plant species. Local farmers in Balikpapan report seeing proboscis monkeys visiting the newly planted areas and feeding on the shoots of young rubber trees. It is likely that the 1.42 km^2 of forest lost to the rubber plantations will gradually turn into proboscis monkey habitat, as the plantations grow tall. However, this should not be expected in the case of industrial-scale intensively managed plantations, which may remain inhospitable for the proboscis monkeys. The emerging risk of industrial-scale forest conversion into forestry plantations should therefore not be underestimated.

4.5. Forest fires

Most of the proboscis monkey’s habitat loss in Balikpapan Bay caused by fire is not attributable to wildfires; instead, the trees were felled and burnt deliberately. When the deliberately burned area got converted to agriculture or other development, we have attributed the forest loss to this ultimate cause in our analysis. Some cases of deliberate forest fires were however not followed by any subsequent development; these cases were typically linked to unsuccessful land speculations, after which the forest is left to slowly regrow.

According to Stark et al.’s (2012) PVA, wildfires caused by El Niño oscillations are supposed to be the major factor that determines the future development of this population. This is however not supported by our data. In 2015, a prolonged ENSO caused extensive wildfires, burning down several areas in and around Sungai Wain Protection Forest (Pro Natura Foundation, 2016). The forest burned mainly along the ridges and on the slopes of hills, destroying valuable wildlife habitat, yet the proboscis monkey habitat, which is mainly located along riversides and the coast, apparently remained relatively humid even during prolonged droughts, and therefore did not burn. (Fig. A2).

This finding however cannot be generalized to all proboscis monkey habitats. Locations without steep slopes, or forests on highly flammable peat soil, would burn rather swiftly, resulting in a loss of vast portions of proboscis monkey habitat. Such scenarios have already happened in Tanjung Puting and Muara Kaman, Kalimantan (Yeager et al., 2003), in Klias Penisula, Sabah, (Sha et al., 2008; Henry Bernard, pers. comm), or are likely to happen, for instance in Danau Sentarum National Park (Stark et al., 2012).

5. Conclusion

The main causes of proboscis monkey habitat loss in Balikpapan Bay were similar to the situation described for other sites in last decades, but the situation has been largely changing in the past 17 years. While the majority of the habitat survived the past history of aquaculture, as well as the forest fires, it was nevertheless devastated by the spread of oil palm plantations. Once most of the suitable land was converted to plantations, the subsequent industrial expansion became the most considerable threat to proboscis monkeys in Balikpapan Bay. In contrast to this forest loss however, the regenerating abandoned aquaculture ponds and secondary forests may represent a new habitat for proboscis monkeys.

The role of conservation efforts in maintaining the relatively slow rate of habitat loss in Balikpapan Bay is apparent but not easy to quantify, as it interplays with other complex economic, demographic and political factors. It is however very likely that one of the reasons for the slowed rate of habitat loss after 2007 is the regular monthly monitoring since 2008 until now. The monitoring is conducted by a team of local fishermen who asked not to be named for security reasons. They collect data on observable human activities within the selected area of Balikpapan coast. Although they have no enforcement power, their regular reports to the local government and NGOs have helped to expose the destructive, often illegal activities, from an early stage. This has helped to prevent at least some of the destructive developments.

The conservation movement in Balikpapan Bay is strongly opposed by the large corporate interests and lacks genuine support from the government. Raising awareness among local citizens may help in pursuing environmental causes, as

illustrated by the protests against dolphin circuses in 2017, resulting in a written commitment of the Mayor of Balikpapan to ban animal exploitation in Balikpapan (Pernyataan Komitmen Balikpapan Bebas Eksploitasi Satwa, 31st Januaary, 2017). The proposal to classify Balikpapan Bay as a provincial marine protected area (Kawasan Konservasi Perairan), which has been submitted to the Governor of East Kalimantan by a multi-stakeholder coalition (Koalisi Masyarakat Pengusul Kawasan Konservasi Perairan di Teluk Balikpapan) on 16th of November 2017, currently remains the major hope for its proboscis monkey population.

In August 2019, the President of Indonesia announced translocation of the national capital from the overcrowded and sinking Jakarta to a large area on the boundary of the PPU and Kutai Kartanegara Regencies. The new capital is expected to cover over 200,000 ha of the land which currently is mostly covered with forest, and the completion date was set on 2024 (Gokkon, 2019). This is likely to result in the next dramatic change in the rate and causation of the proboscis monkey habitat loss in Balikpapan Bay. This report can serve as a source of baseline data, which can be used to assess the future impact of the capital city translocation on the remaining habitat of endangered species.

Ethical standards

None.

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Declaration of competing interest

We declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2019.e00863.

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