Status of Proboscis Monkeys in Kota Belud, Sabah, Malaysia: Insights from Population Surveys and Habitat Assessment

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Abstract: Proboscis monkeys, an iconic Bornean endemic species, are facing threats from habitat loss, degradation, and fragmentation due to human activities. Past surveys have covered only a limited number of proboscis monkey populations across their range, leaving the status of many populations largely unknown. We surveyed the previously unexplored Kota Belud region in northwestern Sabah, Malaysian Borneo, to determine the population and distribution of proboscis monkeys. Our assessment of the threats to their survival focused specifically on land-use and land-cover patterns, with the primary goal of evaluating the population status of proboscis monkeys in this region through an analysis of habitat change. Between January and September 2022, we conducted boat-based surveys in wetland forests—potential habitats of the proboscis monkeys. Of the six sites we surveyed, we directly observed proboscis monkeys at just one, although local residents reported their presence at other sites. Our observations identified 25 individuals in at least three one-male-multifemale groups and one all-male group, all along the Tempasuk River near the coastline. Overall, our study highlights the concerning state of the proboscis monkey population in Kota Belud, which is small, highly fragmented, and likely reaching its limits of adaptability to habitat changes due to human activities. While acknowledging the need for further studies, urgent conservation strategies are needed. For the long-term survival of the proboscis monkeys in Kota Belud, we recommend prioritizing the identification and protection of remaining habitats, rehabilitation, reconnection of isolated areas, and proactive measures to prevent further habitat fragmentation.

Key words: Population status, proboscis monkey, *Nasalis larvatus*, population surveys, habitat assessment, Kota Belud

Introduction

Tropical forest degradation, fragmentation, and loss caused by human activities are a global concern, threatening the diverse flora and fauna and pushing many populations toward extinction (Whitmore and Sayer 1992). Borneo, a recognized center of endemism in Southeast Asia's global Biodiversity Hotspots, is particularly at risk due to illegal hunting and forest conversion for agriculture (Bennett *et al.* 2000; Myers *et al.* 2000; Sodhi *et al.* 2004; Corlett 2007; Fitzherbert *et al.* 2008; Woodruff 2010; Abram *et al.* 2014; Brodie *et al.* 2015). Arboreal primates, which rely heavily on extensive forested areas, face heightened vulnerability to habitat loss and fragmentation (Marsh and Chapman 2013). Consequently, some primates in Borneo, particularly those with limited distributions and specialized habitat requirements, are under significant risk of both local and global extinction (Meijaard and Nijman 2000b; Abram *et al.* 2015; Sha *et al.* 2019; Sha *et al.* 2022). The proboscis monkey (*Nasalis larvatus*), an iconic Bornean endemic, is one such species.

The proboscis monkey has been categorized as 'Endangered' on the IUCN Red List of Threatened Species since 2000 (Boonratana *et al.* 2021), and is protected under CITES Appendix I that prohibits international trade (UNEP-WCMC 2003; IUCN 2008). Found across all political divisions in Borneo, including Sabah, Sarawak, Kalimantan, and Brunei, proboscis monkeys receive the highest protection status under local laws throughout their range (Lhota *et al.* 2019). Their habitats are specific—primarily lowland

wetland forests along rivers and coastal areas such as riverine, mangrove, peat swamp, and freshwater swamp forests (Meijaard and Nijman 2000a; Sha *et al.* 2008). While these habitats have historically offered some protection from human activities due to their relative inaccessibility, modern technology and mounting human socio-economic development activities such as logging, agriculture, aquaculture, urban expansion, industrialization, and infrastructure development increasingly threaten the monkeys' habitats (Boonratana 2013; Gaveau *et al.* 2014; Lhota *et al.* 2019; Toulec *et al.* 2020). Therefore, despite the legal protection provided by local laws to the proboscis monkeys in Borneo, the loss, degradation, and fragmentation of proboscis monkey habitats due to these activities remain significant threats to their long-term survival (Meijaard and Nijman 2000a, 2000b; Boonratana 2013; Toulec *et al.* 2022).

In Sabah, northern Borneo, Malaysia, a population survey conducted in 2004/2005 estimated a minimum of 5,907 proboscis monkeys in five main continuous population centers (Sha *et al.* 2008). Long-term monitoring studies in Klias Peninsula and Kinabatangan, two primary proboscis monkey habitats in Sabah, indicated relatively stable populations between 2004 and 2014 (Matsuda *et al.* 2020; Bernard *et al.* 2021). Results of a population viability analysis conducted by Stark *et al.* (2012) supported the stability of the Kinabatangan populations within the 50 years of their modelling period. Matsuda *et al.*(2020), however, observed a significant decline in group size in Kinabatangan over the same 10-year period (2004–2014), suggesting that it is due to the effects of habitat fragmentation. While proboscis monkeys in specific key habitats in a few locations in Sabah have received significant attention through long-term monitoring studies, the status of proboscis monkey populations in many other areas remains poorly understood. Some of these populations are already small and scattered in isolated areas, rendering them susceptible to local extinction even with minor environmental changes (Sha *et al.* 2008).

This paper presents the results of a proboscis monkey survey conducted in Kota Belud, a district in the northwestern region of Sabah. Despite the long-known presence of proboscis monkeys in the area and their significant role as flagship species supporting wildlife-based tourism at least 5 to 10 years ago at certain locations, no formal surveys have been conducted to assess their population. Our main aim was to assess the local status of proboscis monkey populations by collecting baseline data on their distribution and abundance across a number of sites in the district. We also identified the primary habitat types of the proboscis monkeys and analyzed land-use and land-cover patterns to assess the main threats to their survival. By gathering these data, our study provides important insights to inform general conservation strategies with the goal of increasing the prospects for the long-term survival of the species in Kota Belud.

Methods

Study area

Kota Belud encompasses a land area of 1,391 km² (Fig. 1). The recorded human population of Kota Belud in 2000 was 72,357, which had increased by 48% to 107,243 by 2020 (Department of Statistics Malaysia 2020). The district has several protected areas, including the Abai Mangrove Forest Reserve, where regulated extraction of mangrove trees is allowed, and the Kota Belud Bird Sanctuary, which is only marginally protected. This sanctuary consists largely of wet grassland with scattered areas of open water (Payne and Parish 1985).

As in other parts of western Sabah, this region is experiencing rapid development and significant anthropogenic activities, primarily related to socio-economic development. These have resulted in the degradation and alteration of natural forest habitats, especially in and around shoreline areas. Much of the land has been converted into human settlements and agricultural areas, primarily for growing wet paddy, as well as cash crops such as rubber, coconut and, more recently, small- to medium-sized oil palm plantations. Additionally, the construction of linear structures such as roads and bridges has further fragmented the forests into smaller, isolated fragments. At the time of the study, the construction of the major Pan Borneo Highway was ongoing in the area (Cannon 2019).

Boat surveys

To identify survey sites of potential habitats of proboscis monkeys, we used information gathered from tour operators, local villagers, topographical maps, and literature sources (Sabah Wildlife Department 2018; Sha *et al.* 2008). Our focus was on wetland forests, including riparian and mangrove forest, near coastal areas, although we also included other habitats along river systems further inland. These areas are known to be typical habitats for proboscis monkeys (Meijaard and Nijman 2000a; Bernard *et al.* 2021). We prioritized areas with continuous forest in protected areas such as forest reserves, a bird sanctuary, and riparian zones. We also surveyed fragments of suitable forest on private lands near human settlements, agricultural lands, highways, and other disturbed areas. In addition to these, we surveyed potential proboscis monkey populations on islands near mainland Kota Belud.

Because proboscis monkeys inhabit constantly or periodically wet environments, conducting population surveys on-foot is impractical. These monkeys are known to rest near bodies of water, often returning to and sleeping in large, tall trees alongside rivers and coastal areas in the late afternoon before moving back into the forest the following morning (Bennett and Sebastian 1988; Yeager 1989; Boonratana 2000; Matsuda *et al.* 2010; Bernard *et al.* 2011; Feilen and Marshall 2014). The most efficient and effective way to survey their populations, therefore, is by boat (Bennett and Sebastian 1988; Yeager 1989; Boonratana 2000; Matsuda *et*

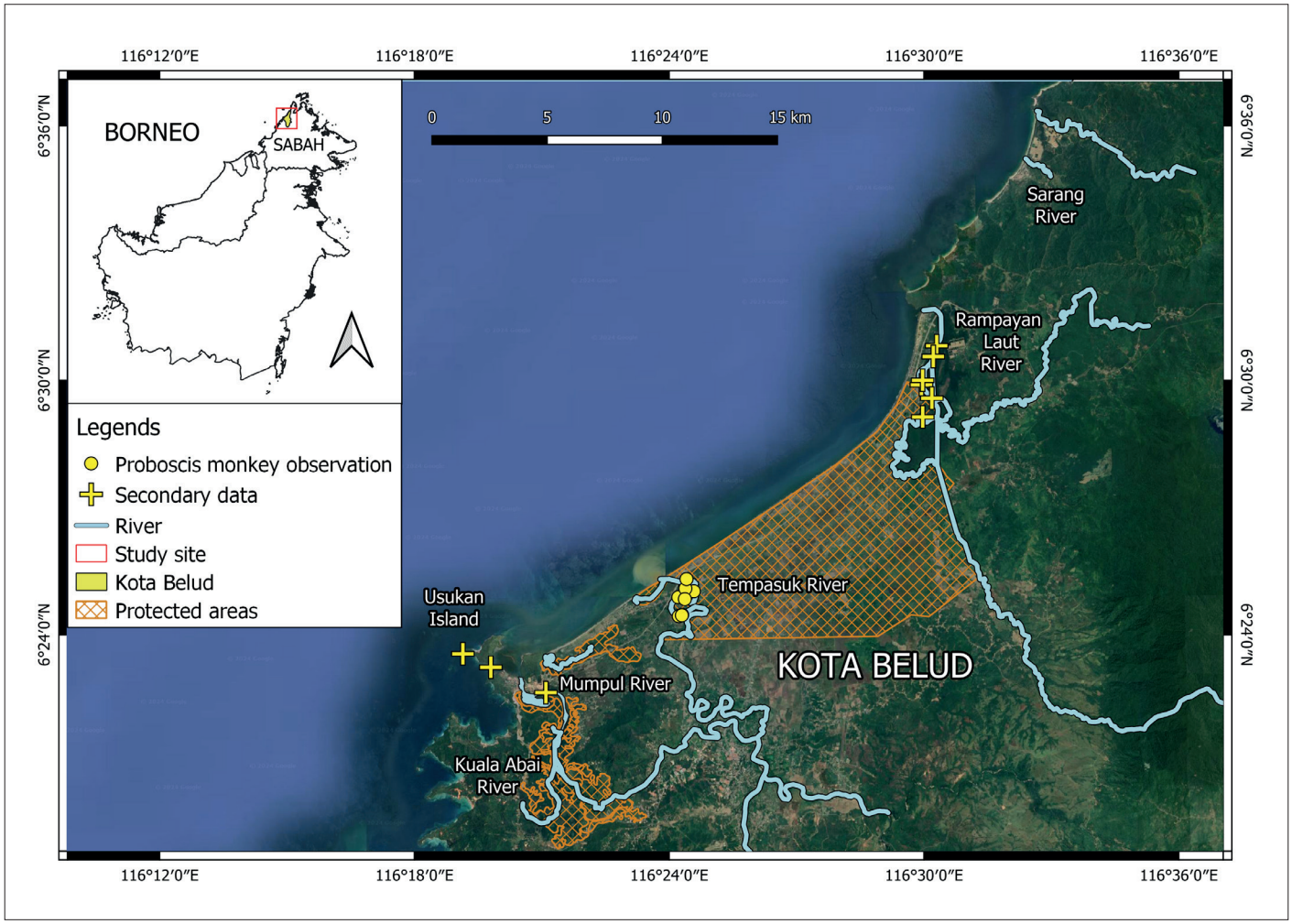

Figure 1. Map of the rivers and other surveyed areas in the Kota Belud district in the northwestern part of Sabah, Malaysian Borneo, and locations where proboscis monkeys were detected based on direct observations and secondary data.

al. 2016). We conducted our surveys either in the late afternoon (16:00–18:30) or early morning (06:00–08:30), i.e., when the monkeys were at their resting sites or before they left them the next day. We used boats fitted with outboard motors to survey all rivers and their tributaries, as well as along coastal forests and nearby islands. The timing of our surveys varied slightly at some sites due to poor weather conditions and/or, during some months, fluctuations in the timing of tides. To ensure accurate data collection, we surveyed sites in close proximity, such as different tributaries of the same river, on the same survey day—either during the morning or evening session. This approach aimed to prevent the possibility of counting the same animals or groups that might have relocated to adjacent sites. For long rivers, our surveys were conducted on consecutive days, with evening sessions covering as much of the river as possible until darkness halted the survey. The following morning, we resumed the survey from the point where we had stopped the previous evening (Sha *et al*. 2008; Matsuda *et al*. 2020).

We used a portable hand-held GPS receiver (Garmin GPSMAP64s) to record our survey routes, marking our advancement at intervals of 50–100 m. During each survey, we had a minimum of one boatman, one assistant to aid in spotting, and a data recorder. Upon spotting proboscis monkeys, we immediately turned off the boat engine and paddled quietly as close as possible to the group. We recorded the location of the group using the same hand-held GPS receiver and counted all visible individuals in the group. The GPS locations of the proboscis monkey groups in our study correspond to the closest possible locations from the monkey groups in the field. We noted the age and sex of each proboscis monkey, classifying them as much as possible to adult males, adult females, subadults, juveniles, or infants. When we were unable to determine their age or sex, we recorded them as unidentified. Using this information, we categorized the groups into three types: One-Male Group (OMG), with one adult male and multiple females; All-Male or Multiple Male Group (AMG); and Solitary Males (Bennett and Sebastian 1988; Yeager 1990; Matsuda *et al.* 2020). We also recorded the type of habitat where the group was found, using a general habitat classification scheme: mangrove, riparian, or mixed mangrove-riparian (Bernard *et al.* 2019).

Besides the primary data, we obtained information about recent proboscis monkey sightings by interviewing selected local residents, including boatmen, in nearby villages and settlements. We determined the approximate GPS location coordinates of the proboscis monkeys based on the information provided by the informants. This information was derived either from the informants pointing to locations on a map where they had observed the monkeys or by the informant showing us where they saw them.

Mapping the distribution of proboscis monkey

To map the distribution of the proboscis monkeys in Kota Belud, we used the GPS location coordinates (latitude/longitude) of the individuals and groups that we obtained from the population survey and informal interviews, importing the data into the Quantum Geographic Information System (QGIS) software version 3.24.3. We overlaid the location coordinates onto a map of Kota Belud using satellite images of the area taken in 2022 obtained through Google Earth Pro version 7.3.

Primary threats based on land use and cover analysis

Human activities resulting in habitat loss, degradation, and fragmentation have been shown to negatively impact proboscis monkey populations (Meijaard and Nijman 2000a; 2000b; Boonratana 2013; Toulec *et al.* 2020). To understand the primary threats to proboscis monkey populations in Kota Belud, we therefore, analyzed the land-use and land-cover patterns by mapping various land-use and land-cover classes within a 2-km distance from the surveyed rivers and other routes, using satellite images taken in 2022. We set a 2-km boundary from riverbanks following Stark *et al.* (2017), as their study using GPS data showed proboscis monkeys can travel up to this distance, although such behavior is not typical. Since there was no previous data on the distribution range of the proboscis monkey in Kota Belud, we assumed that areas near known proboscis monkey habitats were previously suitable habitats for these monkeys.

Results

Abundance and distribution

We identified six potential sites for proboscis monkeys in Kota Belud: Tempasuk River, Kuala Abai River, Rampayan Laut River, Mumpul River, Sarang River and the Usukan Islands (Fig. 1). We conducted two rounds of surveys at each site, except for Usukan Islands, which we surveyed just once. The survey rounds took place from January to June 2022 and then in September 2022. In all, these surveys covered a distance of 74.7 km along rivers and other routes. The first surveys covered 46.27 km, while the second covered 28.43 km.

We surveyed six sites but all eight detected GPS location coordinates of proboscis monkey groups were observed in just one, the Tempasuk River, where we counted at least 25 individuals with a minimum of three OMGs and one AMG (Table 1; Fig. 1). These groups were observed mostly in their sleeping trees, characterized by large, tall trees, overhanging the rivers, situated within a narrow riparian forest (*c.* 30–40 m), which was heavily degraded. We also noted one group foraging on the ground in an area of dense shrubs and creepers but lacking tall trees. All locations where proboscis monkeys were observed in Tempasuk were less than 1 km from human dwellings.

The sighting rates of OMGs in Tempasuk River, as measured by the number of individuals or groups detected per km of surveyed river, was 3.99 individuals/km or 0.64 groups/km. When we considered all six sites surveyed for proboscis monkeys, the sighting rates recorded during the first and second survey round were 0.43 to 0.88 individuals/km or 0.09 to 0.14 groups/km, respectively. The mean group size of OMGs was 7.75 individuals, with a range of three to 10 individuals, with the number of adult females in the OMGs ranging from one to nine per group. The only one AMG detected in this study had four individuals. When detected, the average sighting distance of all proboscis monkey groups was 20 m, with a range of 10 to 40 m.

We obtained nine additional GPS locations of proboscis monkeys from reports by boatmen and interviews with local villagers. In late 2021, a group was sighted in a mangrove near Kuala Abai's estuary. In February 2022, a subadult male was seen swimming towards Usukan Island, approximately 260 m away from the mainland. In May 2022, a proboscis monkey group was reported on Usukan Island. Rampayan Laut River, a popular tourist spot, was reportedly home to six proboscis monkey groups in mangrove forests. In general, proboscis monkeys in Kota Belud were found in three separate areas: Kuala Abai-Usukan Island, Tempasuk, and Rampayan Laut (Fig. 1).

Land use and land cover

Various land use and land cover types were identified, including mangrove forests, other forest types (with many areas of this being in hilly landscapes that may not be very suitable for proboscis monkeys), rice or paddy fields, aquaculture farms, human settlements, swamp areas, and mixed areas. The mixed areas were composed of various community land uses (including oil palm smallholdings), with similar areas also identified but dominated by rubber trees (Table 2, Figs. 2 and 3).

Across the areas surveyed, extents of mangroves (the main habitat for proboscis monkey in this region) were limited, particularly for the Sarang River (Fig. 3) and Tempasuk River sites (Fig. 2). The protection of these mangroves, however, is limited and restricted to Mumpul River and areas along Kuala Abai River, that are designated as Class V Mangrove Forest Reserves, and in Tempasuk, although these areas are within a bird sanctuary (which in effect has little protection, Fig. 2). The large extent of mangrove in Rampayan Laut—potentially the most viable habitat for proboscis monkeys—is not protected (Fig. 3). There has, however, been significant loss and degradation of forest

Table 1. Overall results of proboscis monkey survey in Kota Belud, Sabah, Malaysia.

	River	Distance covered (km)	Survey date	Group ID	Total ind.	Age-sex class						Group type	GPS location coordinates	
						AM	AF	SA	JUV	INF	UF			
1st survey session Jan-Jun 2022														
1	Tempasuk River	6.26	11 Jan 22	NL1_1	9	1	3	2	-	3	-	OMG	06°25'00.0"N	116°2429.3"E
				NL2_1	4	4	-	-	-	-	-	AMG	06°25'08.2"N	116°24'50.6"E
				NL3_1	3	-	-	1	2	-	-	uncertain	06°25'12.0"N	116°24'39.0"E
				NL4_1	5	1	-	-	-	-	4	uncertain	06°24'33.9"N	116°24'30.0"E
2	Kuala Abai River	8.17	8 Mar 22	-	0	-	-	-	-	-	-	-	-	-
4	Mumpul River	2.35	9 Mar 22	-	0	-	-	-	-	-	-	-	-	-
3	Rampayan Laut River	6.50	10 Mar-22	-	0	-	-	-	-	-	-	-	-	-
5	Sarang River	0.39	10 Mar 22	-	0	-	-	-	-	-	-	-	-	-
6	Usukan Island	22.60	8 Jun 22	-	0	-	-	-	-	-	-	-	-	-
2nd survey session Sep 2022														
7	Tempasuk River	6.26	19 Sep 22	NL1_2	6	1	1	3	-	1	-	OMG	06°24'35.8"N	116°24'34.6"E
				NL2_2	3	1	-	-	-	-	2	uncertain	06°24'35.1"N	116°24'34.2"E
				NL3_2	10	1	9	-	-	-	-	OMG	06°25'25.0"N	116°24'40.6"E
				NL4_2	6	1	1	3	-	1	-	OMG	06°24'57.5"N	116°24'38.3"E
8	Kuala Abai River	11.30	20 Sep 22	-	0	-	-	-	-	-	-	-	-	-
9	Mumpul River	1.75	21 Sep 22	-	0	-	-	-	-	-	-	-	-	-
10	Rampayan Laut River	8.73	21 Sep 22	-	0	-	-	-	-	-	-	-	-	-
11	Sarang River	0.39	22 Sep 22	-	0	-	-	-	-	-	-	-	-	-
12	Usukan Island	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: AM: adult male; AF: adult female; SA: subadult; JUV: juvenile; INF: infant; UF: unidentified
OMG: group with one male and multiple females; AMG: all-male group.

Table 2. Land use and land cover types and extents within a 2-km buffer from surveyed rivers.

Land use land cover	Hectares	Percentage
Aquaculture	143	1.45
Beach	4	0.04
Degraded areas	482	4.89
Forest	1,960	19.89
Mangrove forest	1,423	14.44
Mixed areas (smallholdings)	1,277	12.96
Mixed areas/rubber	1,660	16.85
Paddy	1,964	19.93
River	346	3.51
Swamp	148	1.50
Villages/settlements	225	2.28
Areas cleared for the Pan Borneo Highway	221	2.24
TOTAL	9,853	100.00

inside the protected mangrove forest reserve (*c.*300 to 400 ha) in the upper parts of the Kuala Abai River, which may be due to fire and other factors (Fig. 2). The upper reaches of Kuala Abai are a mixture of mangrove and riparian forest, including patches of Nipah palm. The burnt areas were in the forest behind the mangroves on dry land. However, it is possible that other factors, such as siltation and sedimentation, may have also played a role in the degradation of these areas. Approximately 221 ha have been cleared for the construction of the Pan Borneo Highway, resulting in a significant impact on proboscis monkey habitats at Kuala Abai and Rampayan Laut, but most notably at Tempasuk (Fig. 2).

Discussion

Abundance and distribution

The boat-based river census method is known for its efficiency and effectiveness and has been widely used by researchers for surveying proboscis monkeys in wetland habitats (e.g., Sha *et al.* 2008; Feilen and Marshall 2014; Matsuda *et al.* 2016; 2020; Bernard *et al.* 2021). It should be noted, however, that detectability of primates can be

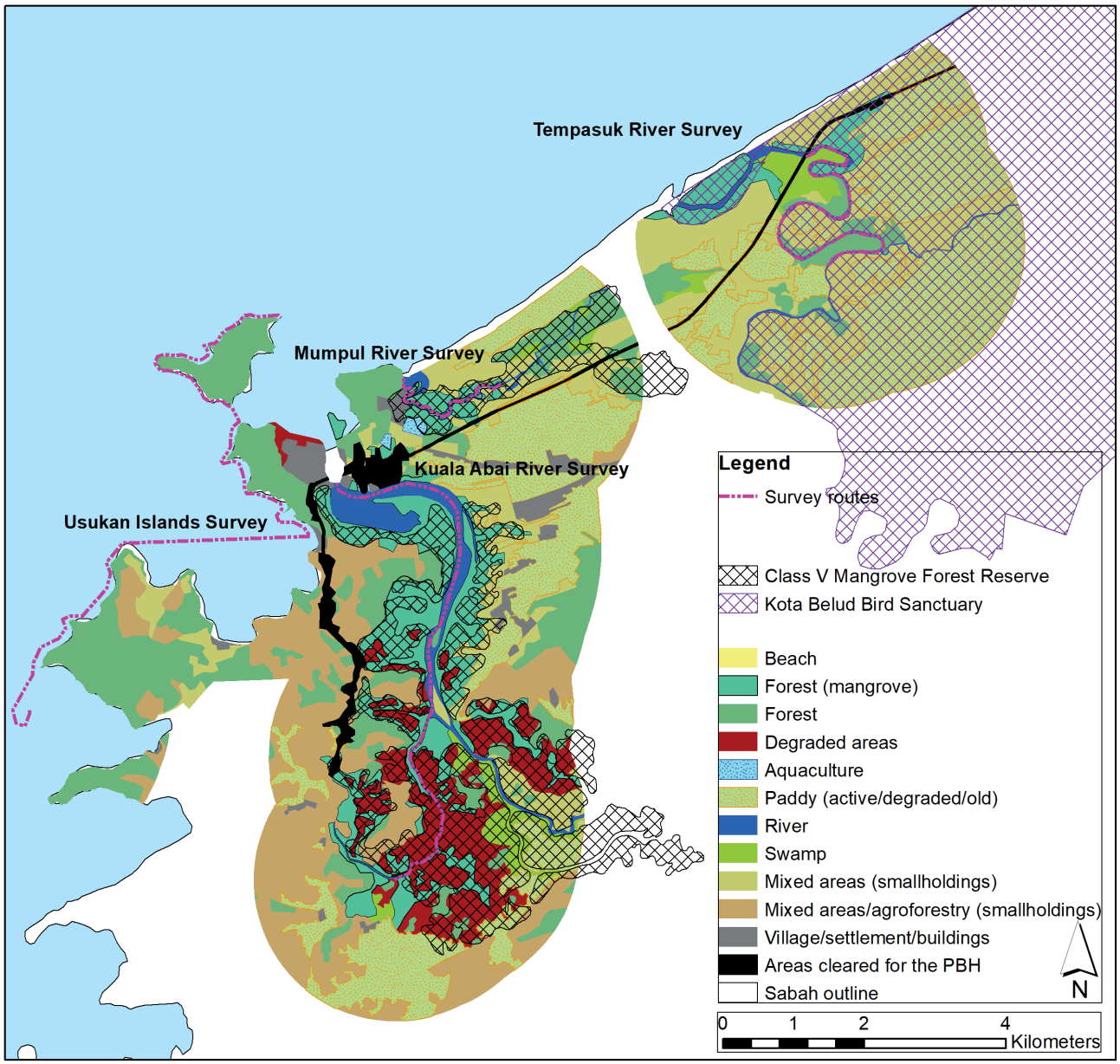

Figure 2. Land use and land cover types within the 2-km distance from the proboscis monkey survey routes in Kuala Abai, Mumpul River, Tempasuk River, and Usukan Island.

influenced by several factors, such as the density and structure of the vegetation and poor weather conditions (Bernard *et al.* 2019; Matsuda *et al.* 2020). The accessibility of survey areas can be influenced by tidal movements along waterways. Our estimated population size of 25 individuals, consisting of at least three OMGs and one AMG, is a minimum count of proboscis monkeys in Kota Belud.

Despite the limitations of this baseline survey, it is evident that the proboscis monkey population in Kota Belud is small compared to other populations elsewhere in Sabah. Previous surveys conducted by Sha *et al.* (2008) in primary proboscis monkey habitat, using a similar census method, albeit without replication but facing similar limitations as in our study, generally reported much higher sighting frequencies, ranging from 1.90 to 8.28 individuals/km or 0.16 to 0.61 groups/km. In contrast, our survey recorded alarmingly low encounter rates of only 0.43 to 0.88 individuals/km or 0.09 to 0.14 groups/km. The absence of proboscis monkeys in the majority of sites we surveyed provides further evidence supporting our perception of a very small population size for proboscis monkeys in Kota Belud.

The average group size of observed OMGs in our study was 7.75 individuals (range: 3 to 10 individuals per group). This group size is smaller than the minimum group size of 10.57 individuals per group (standard deviation of 4.54) documented in Beluran, Sabah by Sha (2006). Furthermore, our findings revealed a highly fragmented proboscis monkey population in Kota Belud, existing in isolated pockets of preferred habitats at three main areas, namely Kuala Abai-Usukan Island, Tempasuk, and Rampayan Laut. The

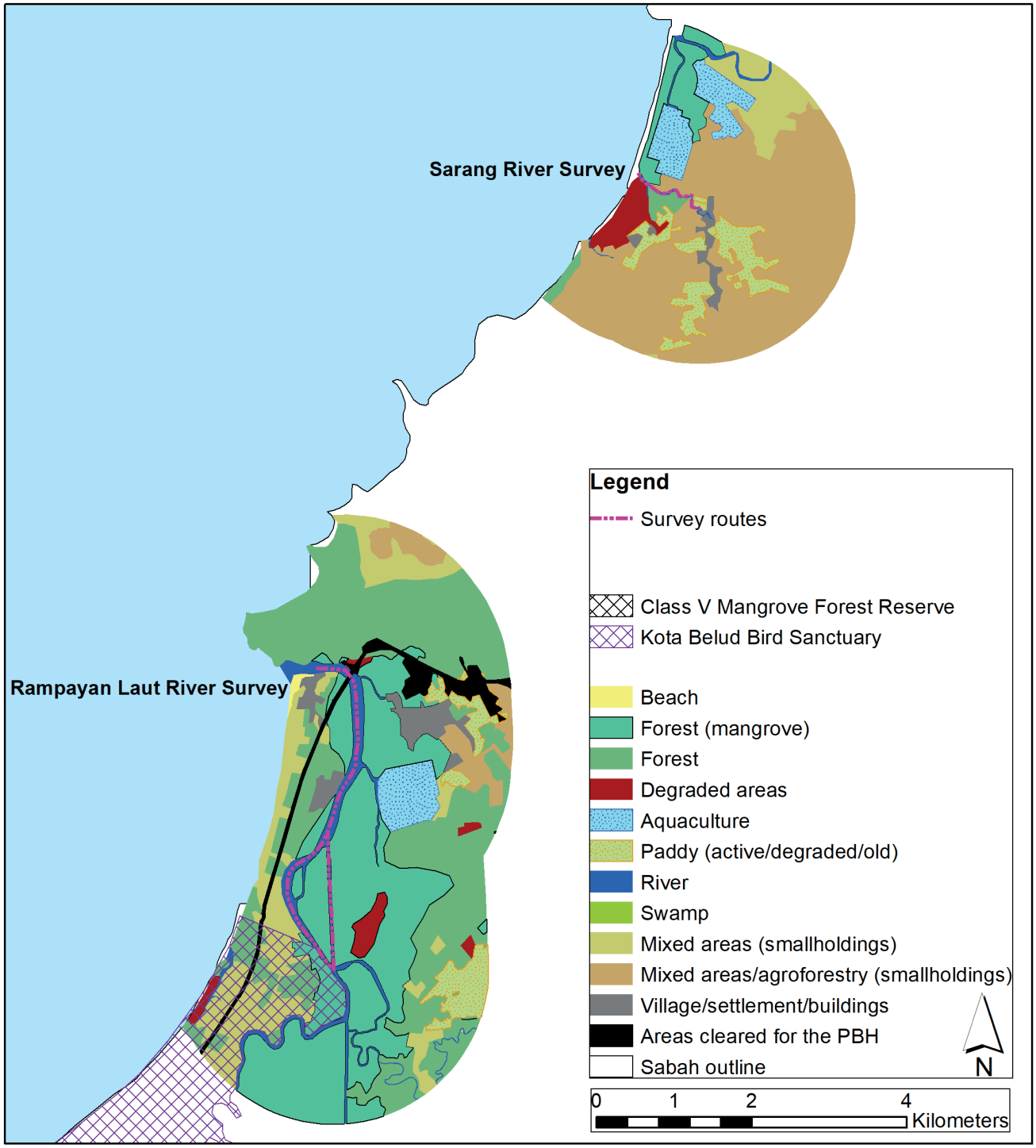

Figure 3. Land use and land cover types within the 2-km distance from the proboscis monkey survey routes in Rampayan Laut and Sarang River.

reduced group and population sizes in Kota Belud could suggest lower carrying capacity in the remaining fragmented habitats for proboscis monkeys. All recorded observations were in riverine forests and coastal mangroves, highlighting the significance of these habitats. The presence of proboscis monkeys further inland, especially in hilly areas in Kota Belud, is unlikely.

Threats from changes in land cover

The proboscis monkey population in Kota Belud faces substantial threats due to habitat loss and fragmentation resulting from human developmental activities. The expansion of agricultural areas, including paddy fields, mixed-use community areas, rubber, and oil palm smallholdings accounts for 4,901 ha (or 49.74%) of previously potentially suitable proboscis monkey habitats. Villages and settlements

make up 225 ha (or 2.28%) of the assessed land areas. The recent expansion of a new highway (221 ha or 2.24%) and extensive degraded areas (482 ha, 4.89%), particularly in the Abai Forest Reserve (possibly due to human-induced fire and other factors), further exacerbate the challenges. The extent of suitable habitat for proboscis monkeys, based on the land use and cover analysis, is 3,383 ha, (34.33%) comprising mangrove forests (1,423 ha or 14.44%) and other forests (1,960 ha or 19.89%). It is important to note, however, that the latter forest category primarily consists of hilly landscapes, which may not be highly suitable for proboscis monkeys, and a large extent of mangrove in Rampayan Laut is not protected.

The proboscis monkey's vulnerability to habitat loss and degradation is heightened by its specific habitat requirements particularly in riparian and mangrove forests (Meijaard and Nijman 2000a; Sha *et al.* 2008). Although proboscis monkeys have been observed in disturbed habitats near human settlements and certain agricultural lands, they avoid other derived habitats and permanent cultivations, such as oil palm plantations (Kawabe and Mano 1972; Mittermeier 1981; Salter and MacKenzie 1985; Soendjoto 2004; Sha *et al*. 2008; Bernard *et al.*, 2021). Any further destruction and fragmentation of their preferred habitats would have a detrimental impact on proboscis monkey populations in Kota Belud.

During our survey, we observed the ongoing construction of the Pan Borneo Highway, which is having a direct impact on mangroves and other forests in Kuala Abai, Tempasuk and Rampayan Laut (Figs. 2 and 3). Our findings suggest that the proboscis monkey population in Abai Forest Reserve may have temporarily migrated to the Usukan Island nearby in response to habitat degradation in the forest reserve and increased noise levels caused by the construction activities of the Pan Borneo Highway. The absence of proboscis monkeys in their previously frequented locations near the Pan Borneo Highway alignment at Rampayan Laut indicates the possibility of similar relocations occurring in other areas. At Tempasuk, this highway is not only clearing proboscis monkey habitat, but importantly splitting habitat and ranges and potentially restricting the movements of this population (Fig. 3). This highlights the influence of the highway on the movement patterns of proboscis monkeys, pushing them to occupy even less optimal habitats and increasing the chance of roadkill (Geraldine 2020; Hui *et al.* 2021). Further research is needed to assess the long-term effects of the Pan Borneo Highway on the proboscis monkey population and to explore possible solutions to enable proboscis monkeys to move safely across this highway.

Interestingly, our study revealed the remarkable adaptability of proboscis monkeys to survive in small, isolated, and degraded forests surrounded by human settlements in Tempasuk. This adaptability is not unique to Tempasuk and has also been observed in other regions such as the Lower Kinabatangan and the Klias Peninsula (Matsuda *et al.* 2020; Bernard *et al.* 2021). Specific environmental conditions in the fragmented forests, such as the presence of remaining tall, overhanging trees along riverbanks, potentially acting as sleeping sites for proboscis monkeys (Boonratana 1993, 2013, 2020; Matsuda *et al.* 2008; Bernard *et al.* 2011; Feilen and Marshall 2014), and their ability to adjust their diet, incorporating more foliage in areas with low tree species diversity, likely contribute to their adaptation to fragmented habitats near human settlements (Bernard *et al.* 2019, 2021).

While these findings highlight the resilience of proboscis monkeys in altered landscapes, they also underscore the importance of even small, degraded forests for their survival amidst human-dominated areas. It is, however, important to recognize the long-term risks faced by small and isolated populations living close to human settlements. These risks include the transmission of diseases or pathogens originating from humans or domestic animals (Wenz *et al.* 2010). Small, and isolated populations in general are also susceptible to the risks of inbreeding and other stochastic factors that can increase the likelihood of local population extinction (Brook *et al.* 2002; Christie and Knowles 2015). While smaller habitat fragments have some value for proboscis monkeys, they are not, therefore, ideal habitats and cannot fully replace extensive and continuous high-quality habitats that are necessary for sustaining viable populations in the long term.

Conservation management

Our analysis of land use and land cover indicates that a significant portion of the assessed areas have been negatively affected by human developmental activities. Considering the small, estimated population size and their fragmented distribution in isolated areas, the proboscis monkey population in Kota Belud is in a critical state and may be approaching its limit of tolerance to habitat change. The status of local proboscis monkey populations, as highlighted in this study, might be a concern in various regions of Borneo. It is imperative to conduct a comprehensive quantitative assessment of the causes and consequences of forest fragmentation across the entire island, using widely accepted methods such as the IUCN-CMP (IUCN & CMP 2012). This approach is essential for exploring potential solutions and preventing the extinction of these local populations (Boonratana 2020). However, it is equally crucial to prioritize the implementation of effective conservation measures specifically in Kota Belud to urgently protect and restore the highly vulnerable proboscis monkey population. With the goal of improving their prospect of long-term survival, we recommend the following measures be implemented with urgency.

Habitat protection

Designate the remaining key habitats, as totally protected areas, or under other legal status that imposes restrictions to prevent further loss of important proboscis monkey habitats. This should include the extensive area within Tempasuk (Fig. 2) and Rampayan Laut (Fig. 3), and other forests along riverbanks and mangroves near the coastline.

While some of these habitats may not currently offer optimal conditions for the long-term survival of proboscis monkeys, our observations suggest that even severely degraded habitats remain important for these primates. To safeguard these habitats, strict regulations and effective enforcement mechanisms should be established to allow early detection of threats and proactively prevent any further loss, degradation, and fragmentation of these critical habitats.

Habitat restoration and reconnection

Implement habitat restoration initiatives, focusing on degraded areas and connecting fragmented habitats. Key sites to restore should include areas between Tempasuk, Mumpul River, and Kuala Abai, to help reconnect these areas and provide more available and accessible habitat for the identified proboscis monkey population in Tempasuk. Further, the extensive degraded areas in the Abai Forest Reserve could also be targeted (Fig. 3). Reforestation should prioritize enrichment by planting native tree species that offer high-quality food sources, resting or sleeping sites, and refuge areas suited for proboscis monkeys (Bernard *et al.* 2019; Oram 2023). The selection of tree species should consider their suitability regarding soil types and other edaphic factors of the restoration areas. Equal emphasis should also be placed on the long-term management and maintenance of these trees (Bernard *et al.* 2019; Oram 2023).

Land-use planning

Develop integrated long-term comprehensive site-specific local land-use plans that consider the conservation needs of the proboscis monkey population in Kota Belud. It is important to promote sustainable land management practices that minimize the ecological impact on proboscis monkey habitats, ensuring their long-term viability and coexistence with human activities. This involves finding a balance between human developmental activities and the protection of their habitats.

Research and monitoring

Set up long-term monitoring and research programs to gather crucial data on the demography, behavior and ecology of proboscis monkeys in Kota Belud, particularly in the context of long-term effects of habitat loss, degradation and fragmentation. Although research and monitoring are not direct conservation actions by themselves, the information derived from these activities will inform conservation strategies and help evaluate the effectiveness of implemented measures and facilitate adaptive management.

Collaborative partnerships

Promote collaborative partnerships among government agencies, research institutions, conservation organizations, and local communities to foster a sense of equal ownership and responsibility, and a collective approach towards proboscis monkey conservation in Kota Belud. To achieve this, we recommend establishing cooperative frameworks that are site specific, such as a management committee that facilitates the sharing of knowledge, resources, and expertise. This committee would be responsible for overseeing the management and implementation of development and conservation activities, with a long-term goal of conserving the proboscis monkey.

Conclusion

Our data indicated the critical situation faced by the proboscis monkey population in Kota Belud with increasing pressure from human development activities. The proboscis monkeys may be approaching their threshold of resilience to habitat changes. The population data we have collected provides an essential baseline for monitoring future trends and evaluating the effectiveness of conservation measures. While we acknowledge the need for further detailed studies, prioritizing the protection, rehabilitation, and reconnection of the proboscis monkey habitats in Kota Belud, and proactive measures to prevent further fragmentation are crucial. Immediate action is essential to secure a sustainable future for the proboscis monkey population in Kota Belud.

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