Artificial Canopy Bridge Design to facilitate Western Hoolock Gibbon (*Hoolock hoolock*) crossing over Mariani-Dibrugarh broad gauge single track Railway Line in Hollongapar Gibbon Sanctuary, Assam

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Front Cover: A female capped langur *Trachypithecus pileatus* with its young crossing the canopy gap introduced by the single-track broad gauge railway line from Compartment-I to Compartment-II within the Hollongapar Gibbon Sanctuary, Assam.
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Back Cover: A male Western Hoolock gibbon *Hoolock hoolock* in the upper canopy alongside the railway track in Compartment-II within the Hollongapar Gibbon Sanctuary, Assam.
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EXECUTIVE SUMMARY

Habitat loss and habitat fragmentation are two principal threats to most terrestrial biodiversity across ecosystems and geographies. Gibbons are a particularly vulnerable group of primates inhabiting the forests of South and Southeast Asia. Of the 20 gibbon species – all threatened, according to the International Union for Conservation of Nature or IUCN – the endangered Western Hoolock gibbon *Hoolock hoolock* is the only one found in India inhabiting the forests in the southern bank of the Brahmaputra-Dibang river system. The Hollongapar Gibbon Sanctuary (HGS) is a small ~21 sq.km Protected Area (PA) in Jorhat, Assam and is one of the species' stronghold supporting around 125 individuals living in more than two dozen family groups. It is also the only PA in India named after a primate species. Apart from the W. Hoolock gibbon, the Sanctuary also harbours six other primate species – capped langur *Trachypithecus pileatus*, stump-tailed macaque *Macaca arctoides*, northern pig-tailed macaque *M. leonina*, Assamese macaque *M. assamensis*, rhesus macaque *M. mulatta*, and Bengal slow loris *Nycticebus bengalensis*, thereby having the distinction of harbouring the highest primate species diversity for any Indian PA.

However, a single track ~1.65 route-km long railway line (currently broad-gauge, but un-electrified as yet) has fragmented the Sanctuary since 1887 into two unequal parts. Over time, the Sanctuary has become a 'forest island' having lost connectivity with surrounding forest patches. Since gibbons are exclusively arboreal animals inhabiting the forest upper canopy, they are particularly sensitive to canopy gaps. Gibbon families on both sides of the railway track have, thus, been effectively isolated from each other, thereby compromising their population genetic variability and further endangering their already threatened survival in the HGS. Worldwide, and even in India, several conservation initiatives have attempted bridging such canopy gaps in forests through artificial canopy bridge (ACB) structures to facilitate arboreal species' movements. The Wildlife Institute of India, Dehradun was approached by the Divisional Forest Officer, Jorhat (Territorial) Division of the Assam State Forest Department (ASFD) to provide specific design inputs towards the installation of such canopy bridges at the HGS. In this context, this report provides design guidelines and considerations as well as specific location-wise details of seven (07) potential sites within HGS for such canopy bridges installation, following thorough literature survey, field data collection and interaction with stakeholders such as ASFD officials and field staff, railway officials and consultants, and local conservationists.

We recognise and emphasise that the design, successful installation and post-installation monitoring of canopy bridges require the involvement of several individuals with professional expertise in fields such as forestry, ecology/primatology, engineering and mountaineering/climbing. Post-installation monitoring of the canopy bridge structures – both behavioural observations of animals around canopy gaps and installed structures as well as through arboreal camera traps to assess bridges' use – is one of the most important

aspect of this project. As is clear, the present un-electrified single-track ~1.65 route-km railway line passing through the HGS has caused distress and posed significant conservation issues to arboreal animals. Hence, a future doubling of the line (if planned) will increase the canopy gap to a large extent and render any conservation interventions (such as ACB installations) futile.

Over the longer period of time, it will be best if the status quo is maintained, although electrification of the existing single track may be permitted subject to necessary statutory approvals with appropriate mitigation and compensation measures implemented after detailed investigation of its ecological impacts. Forest regeneration on both sides of the existing track through afforestation activities to gradually enable natural canopy connectivity, adherence of trains to speed limits when passing through HGS and its Eco-Sensitive Zone/wildlife corridors, ensuring landscape connectivity of the isolated 'forest island' HGS with neighbouring patches of forests, and rerouting of the existing railway line outside Sanctuary limits, and establishing and supporting low-impact home-stay based ecotourism facilities are some of the longer-term interventions necessary to ensure that W. Hoolock gibbons and other canopy-dwelling species persist and thrive within HGS and in the immediate larger landscape.

I. INTRODUCTION

1. Background

The Hollongapar Gibbon Sanctuary (HGS) is located in the Jorhat district of Assam and is spread across an area of 20.98 sq.km. It is bifurcated into two unequal parts by the Mariani-Dibrugarh railway line since 1887, of which ~1.65 route-km (currently single track, broad gauge, un-electrified) passes through HGS (Figure 1). Gibbons are apes in the mammalian family Hylobatidae with four extant genera and 20 species. They are shy, territorial, exclusively arboreal and mostly canopy-dwelling animals, residing in the dense forests of South and Southeast Asia. Adapted to the arboreal way of life, they tend to avoid open spaces and rarely, if ever, come down on the ground where they may become particularly vulnerable to threats such as predation.

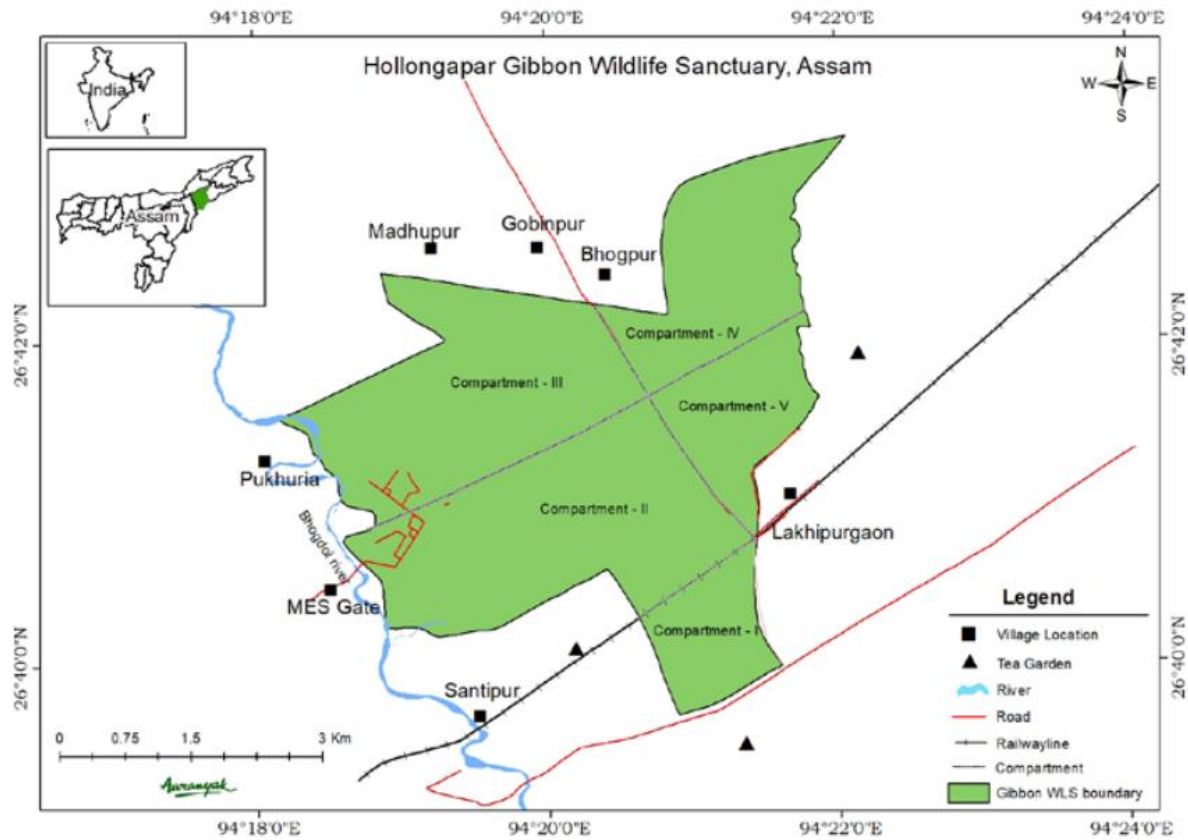

Figure 1: Map depicting location of the Hollongapar Gibbon Sanctuary – note that the Mariani-Dibrugarh railway line (running along a general southwest-northeast direction) cuts across the Sanctuary dividing it into two unequal parts; Hoolock gibbon families residing in Compartment-I (~4-5) have become almost completely isolated due to the rail track-imposed canopy gap and hard forest-human use boundary/ interface (reproduced from Chetry *et al*., 2022)

The Western Hoolock gibbon *Hoolock hoolock* (EN, Brockelman *et al*., 2019) (also interchangeably referred to as 'Hoolock gibbon' in this report) is the only gibbon/ ape species found in India and is accorded the highest legislative protection (placed in Schedule I) under the Wild Life (Protection) Act, 1972. Many studies carried out in India have identified habitat loss, habitat fragmentation, and hunting as some of the most serious threats for this species throughout their entire distribution (Chetry *et al*., 2007). Hoolock gibbons are primarily monogamous and live in small family groups of up to six closely related individuals. Their population at the HGS, Jorhat (around 125 individuals, in 26 groups) is fragmented by the aforementioned railway linear infrastructure (Figure 2) without any effective or substantial canopy connectivity at present. Gibbon families on either side of the railway line – especially the 4-5 gibbon families in the much smaller Compartment-I – remain effectively isolated from each other. The Sanctuary itself has over time become a 'forest island' due to land-use transformation and human-use of surrounding areas. Further plans towards rail track doubling and railway electrification within gibbon habitats thus pose an existential threat to gibbon conservation efforts at HGS.

Figure 2: The single track broad gauge (yet un-electrified) ~1.65 route-km railway line (part of the Mariani-Dibrugarh route) passing within the Hollongapar Gibbon Sanctuary in Assam has created a break in canopy; 12-13 pairs of trains pass through daily in this stretch

In 2015, the North East Frontier Railway (NEFR) authorities along with the Assam State Forest Department (ASFD) had built an artificial canopy bridge (ACB) made of iron at one location across the railway track (Figure 3). However, despite their best intentions, the structure remains unused by arboreal mammals due to several of its design aspects not conforming to gibbons' specialised form of movement in the canopy (brachiation – swinging by arms/forelimbs). A natural canopy bridge (NCB) has developed through long-term plantation activities on both sides of the railway track through joint efforts of Aaranyak (a Guwahati-based conservation NGO) and the ASFD. While plantation/reforestation activities began in 2006, the natural canopy bridge was established/ used by gibbons only by 2019 (Figure 9). Gibbons and other arboreal animals have been demonstrably using the said bridge (Chetry *et al*., 2022). However, this natural connectivity remains tenuous at best since the NEFR regularly trims trees and branches – having the Right of Way (RoW) around the railway line – as part of track maintenance activities.

Figure 3: The iron structure constructed by the NEFR/ASFD in 2015 as a 'canopy bridge' suffers from several design flaws vis-à-vis the target species Hoolock gibbon's preferred mode of locomotion (brachiation) and habits making it unusable for them

The Chief Secretary, Govt. of Assam had raised concerns regarding the threat to Hoolock gibbons by the aforementioned railway line in a Committee meeting on 8th July 2022. It was then decided that the ASFD will provide a canopy bridge design to facilitate gibbon (and other arboreal mammals') movements between the forest fragments (compartments 1 & 2 of the HGS). On 17th October 2022, the Additional Divisional Railway Manager (ADRM), Tinsukia Division, NEFR also requested the Principal Chief Conservator of Forests (PCCF), ASFD to provide designs for canopy bridges. Subsequently, the Divisional Forest Officer (DFO), Jorhat (Territorial) had approached the Wildlife Institute of India, Dehradun (WII) and organised an all stakeholders' meeting – including gibbon conservationists, Railway officials and engineers, and representatives from WII – with the Forest Department on 29th November 2022 at Meleng, HGS to discuss the most appropriate ACB design incorporating domain-specific knowledge of and concerns raised by various agencies (Figures 5 & 6).

On the request of the ASFD (Appendix 1), WII is hereby submitting this detailed report with design inputs towards the implementation of the aforementioned ACBs along with proposed locations for the same, following a field and consultation visit made during November 27-December 02, 2022. The findings and recommendations in this report are expected to be appropriately and urgently acted upon by the ASFD to conserve the threatened Hoolock gibbon population at HGS.

Figure 4: A male Western Hoolock gibbon in Compartment-II of the H. Gibbon Sanctuary

Figure 5: A stakeholders' meeting organised under the chairpersonship of Sh. N. Nandha Kumar (DFO, Jorhat Territorial) with the presence of representatives from Indian Railways/ railways-related consultant organisations, Aaranyak (Dr. Dilip Chetry) and WII, Dehradun (Dr. G.V. Gopi and Sh. Rohit Jha) on November 29, 2022 at Meleng, HGS to discuss design considerations and deliberate on Hoolock gibbon/wildlife conservation aspects

Figure 6: A brief joint field inspection of all stakeholders being led by Sh. N. Nandha Kumar (DFO, Jorhat Territorial) and Dr. G.V. Gopi (Scientist, WII, Dehradun)

2. Objectives & Methodology

The geographical scope of this report is limited to the Western Hoolock gibbon population in the Hollongapar Gibbon Sanctuary (HGS). The objective of this report is to provide a complete guidance towards installing multiple artificial canopy bridge (ACB) crossing structures along the railway stretch passing through the Sanctuary to encourage movement of Hoolock gibbons and other arboreal mammals across the railway track-imposed break in forest canopy. For this, we spent five days during November 28-December 02, 2022 surveying the entire stretch of the railway track passing through the HGS. With the help of experienced field staff, we identified locations where ACB structures could be installed. We also identified 'Post trees' and secondary/web trees (details in Section III) to be used in installing the ACB structures, as well as collected basic details such as their height (visually estimated or through a laser rangefinder, whenever possible), girth at breast height (GBH) (through a measuring tape) and precise locations (through a hand-held GPS device). While formulating the ACB design guidelines and considerations, we have also incorporated concerns shared by Indian Railway and allied agencies during a stakeholders' meeting organised on November 29, 2022 (Figure 5 & 6), and thoroughly read and reviewed available literature on the subject.

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3. Hollongapar Gibbon Sanctuary

Hollongapar Gibbon Sanctuary (HGS) is located in Jorhat district of Assam state in India. It was initially a forest reserve called Hollongapar Reserved Forest which was upgraded to the status of a Sanctuary (under the Wild Life Protection Act, 1972) in 1997 as 'Gibbon Wildlife Sanctuary' – named after India's only ape, the Western Hoolock gibbon (Chetry & Chetry, 2011) (Figure 1). HGS is situated near the Naga hills and Mariani town between 26˚40' to 26˚45' north latitude and 94˚20' to 94˚25' east longitude (Chetry, 2011; Bhattacharjee, 2012; Saikia *et al*., 2017) at an elevation of 100-120 m above mean sea level (Sarkar & Devi, 2017). HGS falls under the globally recognised Indo-Burma Biodiversity Hotspot (Chetia & Kalita, 2012), and is located in the Northeast biogeographic zone of India (North East Brahmaputra Valley biogeographic province – 9A) (Rodgers & Panwar, 1988). HGS receives an average rainfall of about 2490 mm (Ghosh, 2007) while the average temperature ranges between 5˚C to 38˚C (Chetia & Kalita, 2012). HGS has a total geographical area of 20.986 sq.km. The forest type in the Sanctuary is 'Tropical Semi-Evergreen' with subtype 'Assam Plains Alluvial Semi-Evergreen' forests (2B/C1a) harbouring patches of wet evergreen forests (Champion & Seth, 1968; Chetry 2002) (Figure 8). HGS is completely surrounded by tea gardens/ estates (established during 1880-1920) and few villages at its fringes such as Madhupur, Gobindpur and Bhogpur (Verma *et al*., 2012). Major water course of the Sanctuary is one of the tributaries of Brahmaputra called Bhogdoi River, flowing in the general southeast to northwest direction (Bhattacharjee, 2008).

Figure 7: A total of seven primate species – including the globally threatened Stump-tailed macaque *Macaca arctoides* – inhabit the Hollongapar Gibbon Sanctuary, the highest primate species diversity recorded for any Protected Area in India

Apart from the Hoolock gibbon, HGS also shelters the Bengal slow loris *Nycticebus bengalensis* (EN, Nekaris *et al*., 2020a) – the only nocturnal primate found in northeastern

India. Other primates residing in the Sanctuary are stump-tailed macaque *Macaca arctoides* (Figure 7), northern pig-tailed macaque *M. leonine*, eastern Assamese macaque *M. assamensis*, rhesus macaque *M. mulatta* and capped langur *Trachypithecus pileatus* (Chetry *et al*., 2022). Other arboreal mammals found in the HGS dependent on the dense canopy of its semi-evergreen and evergreen forests include Malayan giant squirrel *Ratufa bicolor* and the parti-colored flying squirrel *Hylopetes alboniger*.

HGS is also home to some unique and rare plant species like Hollong *Dipterocarpus macrocarpus* (also Assam's State tree) which dominate the upper canopy of the forest. It is a tall tree that reaches around 12-30 m height with a straight trunk (Borah *et al*., 2015). Some of the other important trees in the Sanctuary from the perspective of arboreal animals include Sam kothal *Artocarpus chama*, Pan sopa *Michelia montana*, Phul hingori *Castonopsis indica*, Ajhar *Lagerstroemia speciose*, Kenglo *Trewia nudiflora*, Otenga *Dillenia indica* etc. HGS is also home to a broad diversity of vertebrate and invertebrate species. More than 200 species of butterflies (Neog, 2015) and 95 species of spiders (Kalita, 2013) have been documented here, along with as many as 250 species of birds, including the endangered White-winged Duck *Asarcornis scutulata* (also Assam's state bird). 41 mammal species such as Asian elephant *Elephas maximus*, tiger *Panthera tigris*, leopard *P. pardus*, leopard cat *Prionailurus bengalensis*, sambar *Rusa unicolor*, barking deer *Muntiacus vaginalis*, wild pig *Sus scrofa*, Chinese porcupine *Hystrix brachyura*, Chinese pangolin *Manis pentadactyla* among others have also been recorded from the Sanctuary (Chetry *et al*., 2001).

Figure 8: Evergreen and semi-evergreen elements populated by very tall trees (with network of climbers and lianas) and a generally connected/closed canopy are some of the distinct flora/vegetation features of the Hollongapar Gibbon Sanctuary, Assam

II. CANOPY BRIDGES FOR PRIMATES

Increasing human population over the last few decades has necessitated an increase in land acquisition as well for various human-use purposes. Many human settlements occur near or surrounding forest areas which create a demand for building infrastructure through these forests to connect different settlements. Many such infrastructures are linear in nature such as roads, railways and pipelines, which create wide forest gaps that fragment natural forest habitats and act as barriers to animal movement. Other anthropological activities such as mining, maintaining agricultural fields and even natural calamities like landslides have contributed towards formation of forest gaps. These barriers affect access to resources such as food and potential mates, thereby restricting gene flow and leading to population declines over time.

Arboreal animals – including many primate species groups like gibbons, guenons, macaques, lorises and lemurs – are especially affected by these linear infrastructures as they break the natural canopy cover and fragment their forest habitat. Since arboreal animals are adapted to life on trees, their body type can support limited types of locomotion including climbing, leaping, brachiating and clinging. Primates like gibbons are known as "*true brachiators*" (Cheyne, 2010). Their extended forelimb, stiff ribcage, presence of long thumb away from the other hook-like fingers (Figure 8) and relatively small body size allows them to use natural substrates like tree branches and trunks for brachiation – a type of suspensory movement using only the forelimbs while propelling the body forward. Given the physical limitations of these species as well as their preference to move in dense canopy cover amongst high trees, it is unnatural for them to climb down and move on ground with open canopy for crossing wide forest gaps like roads, railways, pipelines etc. In addition to the risk of vehicle collision, primates like gibbons also fear the increased chances of predation on ground.

Figure 9: Photos of wild gibbons showing difference in length between the thumb and other fingers, allowing them to get stronger grip on substrates like tree branches (reproduced from Cheyne, 2010)

Since crossing forest gaps like roads and railway lines cause stress to such species adapted to arboreal living, one effective mitigating measure taken around the globe is the construction of canopy bridges across such forest gaps to mitigate damage. Canopy bridges are bridges or connections through high rise trees in order to allow tree-dwelling animals to cross forest/canopy gaps to meet their different purposes including dispersal, foraging (access to resources), mating etc. They may be of the following main three types.

1. Natural Canopy Bridge (NCB)

These bridges are made out of naturally occurring components or materials such as bamboo (Das *et al.*, 2009; Linden *et al*., 2020) and tree branches (Chetry *et al*., 2022). In a study conducted by Linden *et al.* (2020) in South Africa, two types of bridges were constructed to facilitate the movement of Samango monkey *Cercopithecus albogularis* across a forest gap created by a road. Of the two designs, the species was clearly observed using the natural single bamboo pole bridge more than the semi-artificial ladder-rope bridge made of nylon and wood. This could be a matter of familiarity with the substrates used. Their behaviour such as running, especially in the juveniles – alluding to their level of caution – was also found dependent on the extent of canopy cover (more urgent under open canopy). Thus, preserving the natural canopy cover during road/linear infrastructure construction is recommended wherever possible. Otherwise, building single (or network of multiple) pole(s) across canopy gaps using bamboo has been found to be effective, for e.g. as documented by Das *et al*. (2009) at Bherjan Borajan Podumoni Sanctuary, Assam for the Western Hoolock gibbon. Gibbons were documented regularly using these bridges on which they either brachiated or walked bipedally for crossing the forest gap. It is generally found that the habituation period of animals/target species to NCBs is almost immediate.

While installing such bamboo poles may be convenient, certain natural bridges such as those made using tree branches may take longer time to establish. One such bridge has gradually established in the HGS itself, as mentioned above. In 2006, >3000 saplings of trees were planted, particularly consisting of 71 species known to serve as food sources and sleeping trees of gibbons. After 13 years of this plantation drive, in 2019, branches of three trees along the railway track grew and formed overlaps among them, building a natural canopy bridge across the track (Figure 10). Gibbons were thereafter documented using the bridge almost as soon as it was established (Chetry *et al*., 2022). Other arboreal species that benefitted from this conservation intervention included squirrel *Sciurus sp*., rhesus macaque, capped langur and Assamese macaque (Das *et al*., 2009; Linden *et al*., 2020; Chetry *et al*., 2022).

Figure 10: NCB connecting two forest compartments in the HGS, Assam – A. Tree branches starting to overlap with each other across the railway line barrier (2019); B. Mature tree branches have formed strong overlaps across the railway line and continue to grow (2021) (reproduced from Chetry *et al*., 2022); however our field visit in November 2022 revealed that this canopy connection has thinned recently due to one of the trees constituting the NCB being significantly damaged by a recent storm event

2. Semi-Artificial Canopy Bridge (SACB)

Semi-artificial canopy bridges (SACB) are made using a combination of natural and man-made materials or components such as a rope-ladder made using wood and nylon rope (Linden *et al*., 2020) and liana plants secured to trees using nylon hitch (Balbuena *et al*., 2019). An SACB structure was established by Balbuena *et al.* (2019) in the Peruvian Amazon across a natural gas pipeline Right of Way using a single liana to allow arboreal animals to cross the gap (Figure 11). Animals such as kinkajou *Potos flavus*, black-headed night monkey *Aotus nigriceps*, brown-eared woolly opossum *Caluromys lanatus*, eastern lowland olingo *Bassaricyon alleni* and few other species were found successfully using the bridge after seven days of its installation (Figure 11). Thus, the habituation period to SACB is relatively short. In addition, its construction saves time and energy given that, in this example, one bridge took only 20 man-hours to get completed. According to a study conducted by Linden *et al.* (2020) in South Africa, a semi-artificial bridge using nylon and wood was constructed specifically for Samango monkey *Cercopithecus albogularis*. However, its use was not found as efficient as natural canopy bridge made up of a single bamboo pole. It could be due to unfamiliarity of the species with the substrate used in the SACB design.

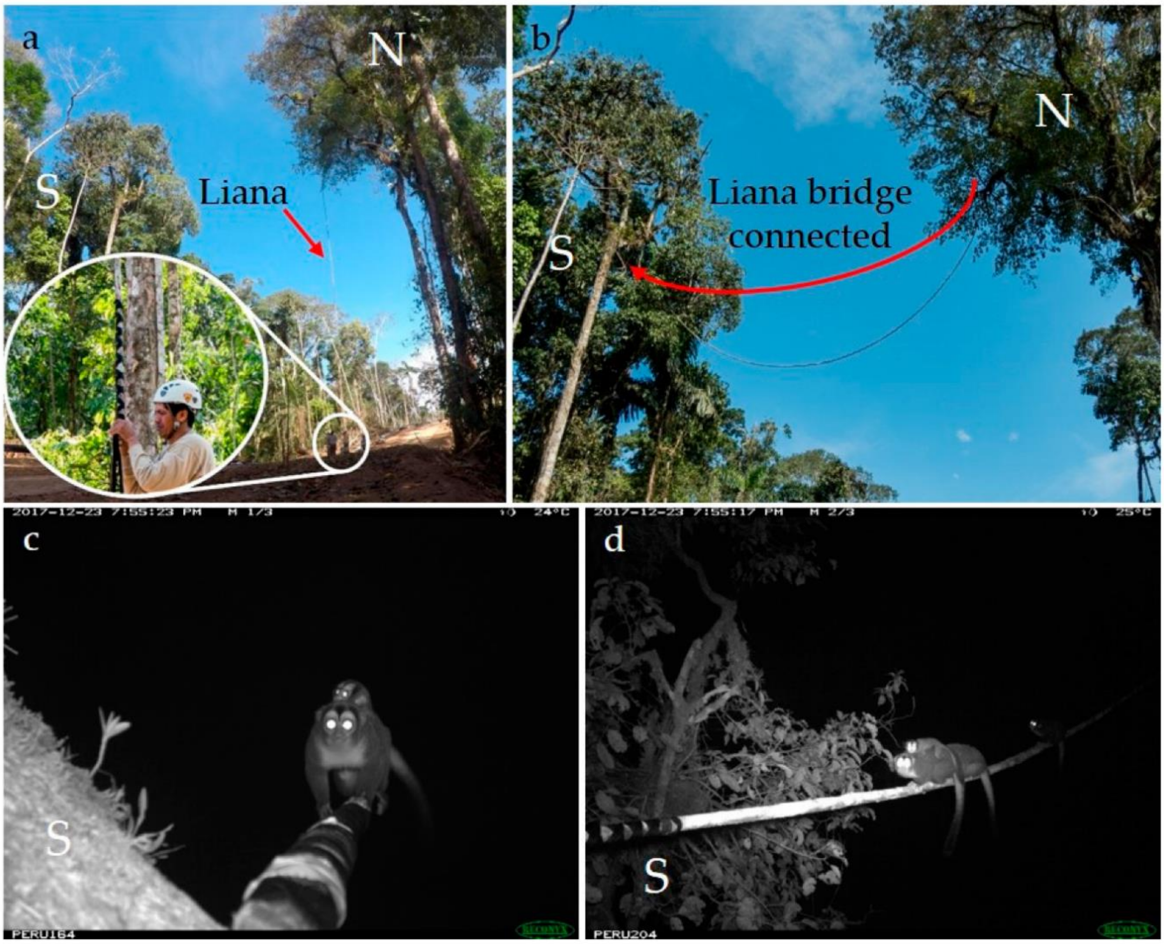

Figure 11: Installation of SACB made of liana in the Lower Urubamba Region (LUR) of the Peruvian Amazon – a. securing the braided nylon webbing hitch at the tip of the liana; b. suspending the liana by pulling down the paracord line attached to the webbing (red arrow shows the final location of the liana); c. & d. camera showing the liana bridge, capturing a crossing by a family of night monkeys (reproduced from Balbuena *et al*., 2019)

3. Artificial Canopy Bridge (ACB)

These bridges are made using artificial or man-made materials/ components such as water-pipe (Birot *et al*., 2020), mountaineering grade ropes (Chan *et al*., 2020), wood and cable (Mass *et al*., 2011), PVC conduit pipe, pressure pipe, galvanised wire and turnbuckles (Cunneyworth *et al*., 2022), fire hose pipes (Yapa *et al*., 2022), synthetic polypropylene rope (Flatt *et al*., 2022) etc. Habituation period for ACBs are slightly longer as compared to both NCB and SACB. In West Java, Indonesia, the Javan slow loris *Nycticebus javanicus* got habituated to both waterline and wire (wrapped with rubber) bridges within 12.9 days on an average after their installation (Birot *et al*., 2020), while Hainan gibbon *Nomascus hainanus* in Hainan Bawangling National Nature reserve of China took around 176 days to habituate to the installed double-rope bridge (Chan *et al*., 2020). In another study from West Java, Indonesia, Nekaris *et al*. (2020b) reported that Javan slow loris took around 10 days to get habituated to the installed waterline bridges, whereas the Javan palm civet *Paradoxurus musanga javanicus* took around 36 days. In addition, ACBs are relatively expensive to install with establishment cost ranging from 157 to 5000 USD (Mass *et al*., 2011; Chan *et al*., 2020; Cunneyworth *et al*., 2022).

Figure 12: Photos showing two types of ACBs made of waterpipe (left) and a 1.5 cm width wire wrapped with rubber (right) for Javan slow loris use in Cipaganti, West Java, Indonesia (reproduced from Birot *et al.*, 2020)

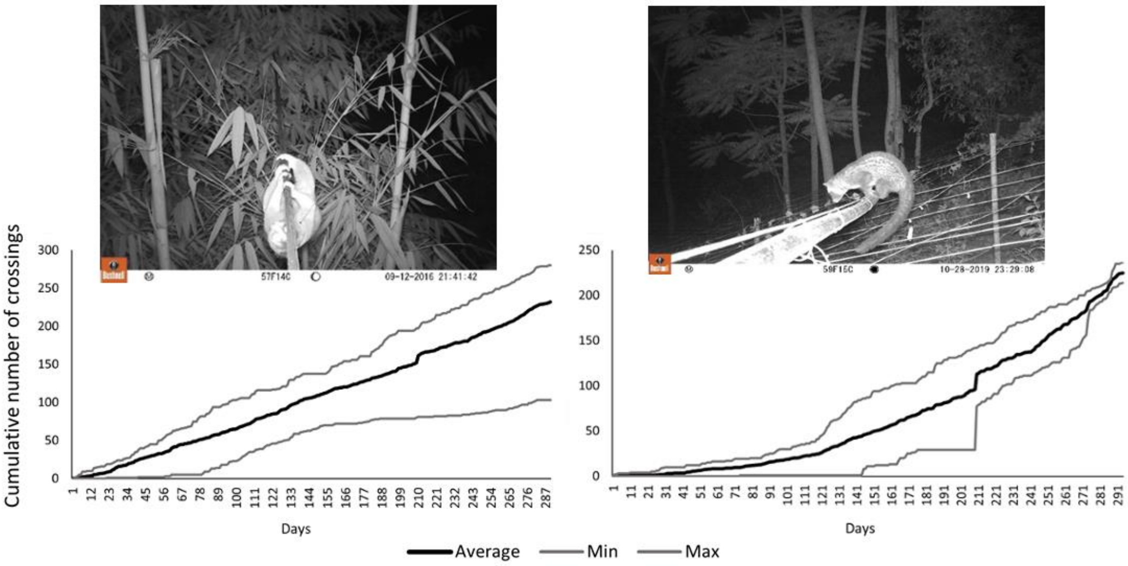

Figure 13: Mean (in black) and range (in gray) cumulative number of crossings on rubber bridges (left) by Javan slow loris and on waterline bridges (right) by Javan palm civet in Cipaganti, West Java, Indonesia during 2017-2019 (reproduced from Nekaris *et al*., 2020b)

Figure 14 : The endangered Lion-tailed macaque *Macaca silenus* – endemic to India's Western Ghats – using a rope-lattice type ACB (made of rubberised canvas from used fire hosepipes) installed over a road in the Anamalai Hills of Tamil Nadu (photograph: Dhritiman Mukherjee)

Figure 15: Use of ACB (double-rope bridge) in China by the world's most critically endangered primate, the Hainan gibbon *Nomascus hainanus* showing four modes of locomotion on it – a. climbing (hand-railing), b. climbing (underneath); c. walking, and d. brachiation (reproduced from Chan *et al*., 2022); the design guidelines in this report for ACB installation at HGS to facilitate W. Hoolock gibbon movements across forest canopy gaps is based largely upon this successful example

ACBs have been found to be successful for other primate and non-primate arboreal species such as Pallas's squirrel *Callosciurus erythraeus*, small flying squirrel *Hylopetes sp*., lemur sp. (Lemuriformes), squirrel glider *Petaurus norfolcensis*, sugar glider *Petaurus breviceps*, Common brushtail possum *Trichosurus vulpecula*, feathertail glider *Acrobates pygmaeus*, common ringtail possum *Pseudocheirus peregrinus*, Angolan Colobus monkey *Colobus angolensis*, Sykes' monkey *Cercopithecus mitis albogularis* and Vervet monkey *Chlorocebus pygerythrus* (Goldingay *et al*., 2012; Chan *et al*., 2020; Nekaris *et al*., 2020b; Cunneyworth *et al*., 2022).

4. Summary

We summarise some of the available literature (indicative) and various canopy bridge structure installations to facilitate arboreal mammals' movements in the following three tables.

Bridge type	Context/ Use case scenarios	Pros	Cons
Natural Canopy Bridge (NCB)	NCB is used to connect shorter distances between forest gaps where the use of natural materials for the bridge construction is possible.	• Habituation period for NCB is short due to the use of natural bridge materials such as bamboo, liana and tree branches. • NCB maintains the natural canopy connectivity. • Provides better camouflage to the animal species through the forest, thereby reducing stress and other behavioral changes. • NCB in combination with other natural substrates like lianas and vines can provide additional source of food to the animals (Das et al., 2009). • Cost-efficient than SACB and ACB.	• Duration of constructing a NCB can be longer than SACB and ACB depending on the material. For e.g. more than 3000 saplings of trees were planted along a 1-km stretch of the railway track in Hollongapar Gibbon WLS by the local community/ NGO and Assam State Forest Department with the aim to achieve mature trees with overlapping branches across the track, providing natural crossing opportunities for the residing gibbons. It took 13 years to form natural canopy bridges after the plantation drive. • Strength of NCB is less reliable than a well-constructed SACB and ACB, by which it is preferred only for shorter forest gaps.
Semi-artificial Canopy Bridge (SACB)	SACB is utilised when using natural materials (e.g. liana, climbers etc.) enhance the quality of the artificially built bridge.	• In SACB, the artificial material provides better durability and strength to the bridge while the natural material helps to reduce the habituation period by providing a familiar substrate to the animals for their movement. For e.g., habituation to a single liana bridge by eastern lowland olingo *Bassaricyon alleni* in the Peruvian Amazon was only 7 days after installation.	• Establishment cost is relatively higher than NCB. • In a study done by Balbuena *et al*. (2019), the liana used to make SACB remained intact only for 7 months, after which it broke as it became excessively dry and brittle. Thus, the natural component of the bridge may not last long.

Bridge type	Context/ Use case scenarios	Pros	Cons
Artificial Canopy Bridge (ACB)	ACB constructed where forest gaps are large and availability of natural canopy is less. Such areas need bridges with greater strength and durability to prevent crossing accidents. ACB also preferred when canopy regrowth cannot occur in an area after the construction of a linear infrastructure.	• Establishment duration of the bridge shorter than NCB, given that the design is not too complex. For e.g., a single rope bridge using synthetic polypropylene rope was established in 30 minutes and installed in 4 hours as recorded by Flatt *et al*. (2022) in Costa Rica. • ACB can be used to serve other purposes as well. For e.g. waterpipes are used in West Java, Indonesia as canopy bridges, which is also used by farmers for irrigation purposes in the nearby agricultural fields.	• Habituation period is longer in ACB as animals take time to explore the new substrate of the bridge in their natural habitat. • Establishment cost is relatively higher. A ladder bridge made using PVC pipes and zip-line cost around 937 USD (Flatt *et al*., 2022). • More chances of making human error while constructing the bridge leading to a direct impact on the physical ability of the animals using them. • Uncertainties are involved with introducing unnatural substances in the wild.

Table 1: Summary describing use-case scenarios and various pros/cons of the three main types of canopy bridges – natural, semi-artificial and artificial – used to facilitate arboreal animal movements and connect habitat patches

Sr. no.	Target arboreal species; Location/ Country	Type of canopy bridge; Bridge design & materials used	Barrier/ Gap & Habituation period	Reference/ Source
1	Lemur *sp*. (Lemuriformes) – Madagascar, Africa	ACB – Suspension bridge made of wood; plank bridge made of wood & cables	Road & pipeline; habituation period not available	Mass *et al*., 2011
2	Javan slow loris *Nycticebus javanicus* – West Java, Indonesia	ACB – Rigid water pipe tied to a wire; rubber wrapped around a wire	Agricultural fields; 12.9 days habituation period (on average)	Birot *et al*., 2020
3	Samango monkey *Cercopithecus albogularis* – northern South Africa	NCB and SACB – Single pole bamboo trunks and ladder rope bridge using nylon and wood	Road; habituation period not available	Linden *et al*., 2020

Sr. no.	**Target arboreal species; Location/ Country**	**Type of canopy bridge; Bridge design & materials used**	**Barrier/ Gap & Habituation period**	**Reference/ Source**
4	Angolan Colobus monkey *Colobus angolensis palliates*, Sykes' monkey *Cercopithecus mitis albogularis*, Vervet monkey *Chlorocebus pygerythrus*, Yellow Baboon *Papio cynocephalus cynocephalus* – Kenya, Africa	ACB – Horizontal ladder-style bridge	Road; habituation period not available	Cunneyworth *et al*., 2022
5	Dusky langur *Trachypithecus obscurus* – Teluk Bahang, Penang, Malaysia	ACB – Firehose bridge (single and double rope bridge)	Road; eight (08) months habituation period after installation	Yap *et al*., 2022
6	Dusky langur *Trachypithecus obscurus* – Thailand	ACB – Electric and telecommunication cables	Not accessible	Aggimarangsee *et al*., 2022
7	Mantled howler monkey *Alouatta palliata palliate* – Costa Rica	ACB – Not accessible	Not accessible	Rojas & Gregory, 2022
8	Primates, especially black Sumatran langur *Presbytis sumatrana* – north Sumatra, Indonesia	ACB – Ladder canopy bridge (material not known due to accessibility limitations to the paper)	Not accessible	Prasetyo *et al.*, 2022
9	Possum *sp.* – Wet Tropics of Queensland, Australia	ACB – Three rope bridge designs: single rope, ladder-like bridges and rope tunnel-shaped bridges; materials include marine-grade nylon rope, plastic spacers and steel cables.	Road; Rope tunnel – 5-17 months after installation (according to different species); Ladder-like bridge – 7 months after installation; Single rope – habituation period not available	Weston *et al.*, 2011
10	Arboreal wildlife, in general (5 mammals and 3 bird species observed using structures) – Osa, Costa Rica	ACB – Single-rope and double-rope using synthetic polypropylene ropes; ladder bridge used PVC pipe and zip-lines.	Road; Single-rope bridge – 31 days for woolly opossum *Caluromys derbianus*; Double-rope bridge – 26 days for kinkajou *Potos flavus*; Ladder bridge – 170 days by woolly opossum	Flatt *et al*., 2022

Table 2: Indicative examples summarising information regarding canopy bridge structures installed successfully for arboreal species (mostly primates) around the globe

Sr. no.	Target arboreal species; Location/ Country	Type of canopy bridge; Bridge design & materials used	Barrier/ Gap & Habituation period	Reference/ Source
1	Hoolock gibbon *Hoolock hoolock* – Bherjan Borajan Podumoni WLS, Assam, India	NCB – single/ multiple bamboo poles	Canopy gap due to selective logging/ deforestation; 14 days habituation period	Das *et al.*, 2009
2	Hoolock gibbon *H. hoolock* – HGS, Assam, India	NCB – Overlapping tree branches after reforestation, mainly by sleeping and feeding tree species used by gibbons	Railway; used almost immediately after formation of NCB	Chetry *et al.*, 2022
3	Hainan gibbon *Nomascus hainanus* – Hainan Bawangling National Nature reserve, China	ACB – two-pronged, double-rope bridge	Canopy gap induced by landslide due to typhoon; 176 days habituation period	Chan *et al.*, 2020
4	White-handed or Lar gibbon *Hylobates lar* – Khao Yai National Park, Thailand	ACB – two single-rope bridges (manila ropes), one nylon rope bridge and a ladder bridge made up of polypropylene rope with PVC tubing rungs	Road; 10 weeks habituation period	Saralamba *et al.*, 2022

Table 3: Indicative examples summarising information regarding canopy bridge structures installed successfully for various gibbon species

III. ACB DESIGN FOR HOOLOCK GIBBON AT HGS

1. Design guidelines and considerations

Learnings derived from experiences of installation of canopy bridges (specifically, artificial canopy bridges) around the world, and from inputs received from the NEFR (Indian Railway) authorities with electrification of the line planned soon (subject to statutory approvals), the following design guidelines and considerations are suggested towards installation of ACBs for arboreal mammals' use (specifically for Hoolock gibbons) at the HGS.

1. The most practical and cost-effective ACB design for Hoolock gibbons may be installing double-rope bridges (following Chan *et al.*, 2020) over the railway line by tying mountaineering-grade nylon static (low stretch) rappling ropes complying to the EN1891 standard (Type A, diameter 12 mm) on two sturdy, tall, mature and undamaged trees (called "post trees") preferably used by Hoolock gibbons for purposes such as feeding, lodging etc. with a large primary branch axis – one on either side located closest to the railway track. As much as possible, there should be no physical impediment along the bridge that might obstruct gibbons' typical brachiating movements. The suspended ropes themselves must have a natural elasticity, making movement along them easy and comfortable.

2. Since the height of the canopy bridge has to account for both sufficient slack and a minimum safety distance from the contact/live wire (to be constructed at maximum 7.2 m height from the railway track), the minimum distance between any ACB component

structure (for e.g., a safety net described below) from the railway track must be at least 11.5 m accounting for slightly more than 4 m safe distance. Since gibbons are group-living animals, the height and potential rope sagging computations must factor in for the bridge usage of multiple individuals (at least 50-60 kg). The post trees, thus, must be chosen accordingly.

3. Since there is always a non-zero probability of an animal accidentally falling off the installed ACB (due to various reasons) and getting either electrocuted or exposing itself to other dangers such as increased predation risk on ground, installation of safety nets below the main twin-rope bridge/span as a fail-safe mechanism may be tried. Such a safety net may measure 2 m in width and be about 3.5 m below the main bridge itself (but at least 4 m above the live/contact wire), and tightened in such a manner so as to be able to bear weight of around 50-60 kg without significant sagging while maintaining a safe distance from the railway overhead equipment/infrastructure.

4. To encourage the use of the main span/canopy bridge, and help gibbons/other arboreal mammals get habituated to the same, as well as to ensure that lateral canopy gaps (if any) around the post trees are also connected, a web-design around the post trees with a single rope connection to 2-4 sufficiently strong/sturdy and mature "secondary" trees (as required) on both sides is recommended. Along such secondary trees/connections, 'stepping-stone' knots could be tied to sturdy branches on any suitable intermediate tree(s) as well. The height (from forest floor/ground) of such secondary connections may ideally be between 11-15 m, while the span is dependent on finding suitable trees.

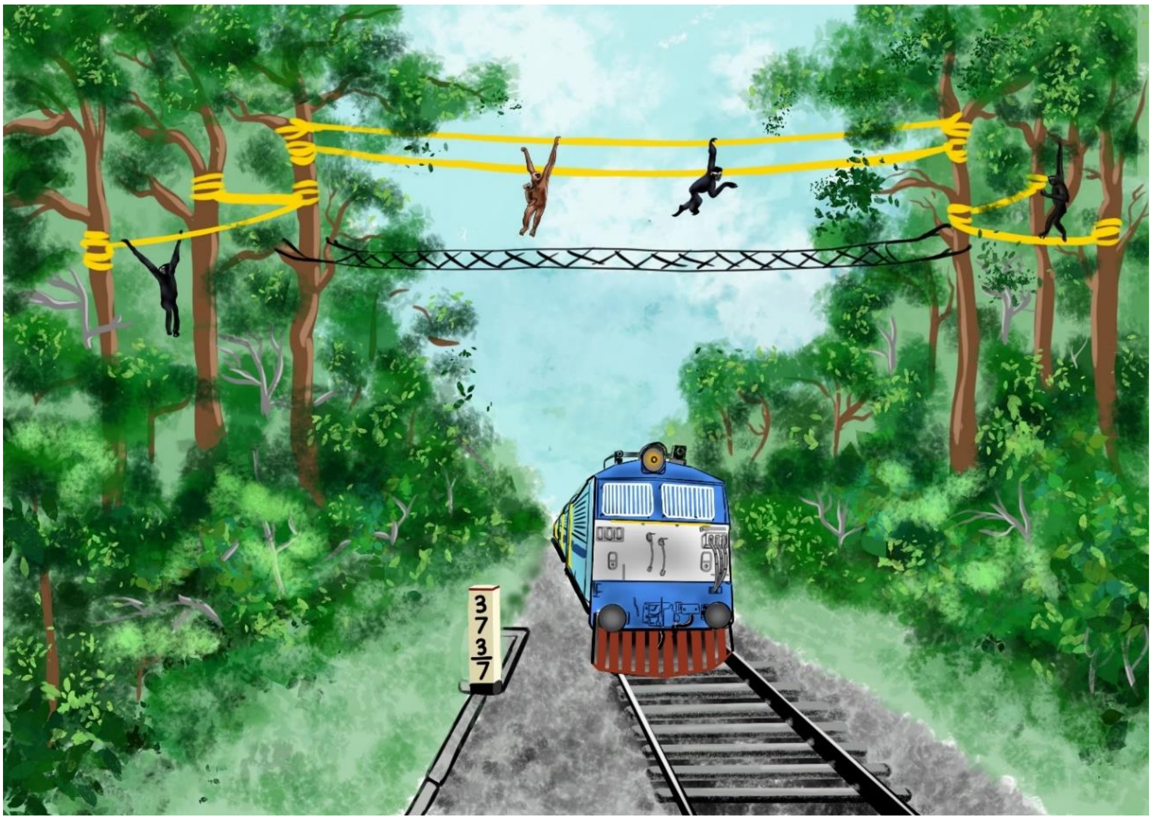

Figure 16: An illustration of the basic artificial canopy bridge design proposed at HGS, Assam (illustration by Vabesh Tripura)

5. Over the longer term, it might be suitable to incorporate natural elements into the ACB structure/design. Lianas and creepers may be 'guided' along the rope bridges so as to help them intertwine and form part of a hybrid (or semi-artificial) design centred around the artificial rope bridge. Such an incorporation will encourage gibbon acceptability of the artificial structures and improve their durability and stability.

Figure 17: An illustrative example of an artificial canopy bridge (distances depicted here are not to scale) design at HGS incorporating concerns shared by Railway authorities factoring in the near-future electrification prospects of the railway line (illustration by Vabesh Tripura)

Certain additional considerations besides the above broad guidelines are as follows –

i. The implementation of ACBs is a technical, collaborative and multi-stakeholder exercise. Accordingly, a committee of diverse and relevant experts comprising of ecologists/primatologists (both government and non-government agencies), foresters along with engineers and expert mountaineers may be constituted to further fine-tune the design and execute/install the structures in the field, and regularly monitor (subsequent to installation) them to assess gibbon and other arboreal mammals' usage. Such a committee will regularly meet (with meeting minutes recorded) to deliberate among themselves and, based on field data, suggest any appropriate modifications and course-corrections. A dedicated maintenance/upkeep and pre-emptive damage control subcommittee may also be setup with clear and fixed responsibilities to ensure all ACB structures are regularly checked for damage and routine maintenance tasks carried out.

ii. Ends of the canopy bridges as well as knots must be secured and well clamped/tightened using appropriate and high-grade fastening materials and techniques. Caution must be exercised to ensure that ropes are tied in a manner that allows trees to grow in girth. Care must be taken to ensure that components and equipment used are durable enough to last several years (given regular maintenance and upkeep) under harsh outdoor environments. It may be feasible to execute the implementation of ACBs at two suggested sites (nos. 4 & 7, see details below) on an experimental basis, assess challenges experienced (if any) and target species' responses post installation, and thereafter install ACBs at other suggested sites from learnings thus derived.

iii. Other than monitoring gibbon/other arboreal mammals' actual use of installed canopy bridges (through camera traps), it may be extremely important to regularly collect behavioural data of arboreal animals in and around canopy clearings and on/over the installed structures, as well as institute longer term population and genetic monitoring programme/studies, to help infer the utility of such structures towards enhancing animal populations and maintaining genetic diversity. Regular training programs for field staff and providing a detailed log/data sheet (in local language) and data collection protocol will help in collecting crucial information in a scientific manner.

iv. It is imperative that the speed of trains themselves passing through the HGS, its ESZ and elephant corridors is regularly monitored using available technology, so that applicable speed restrictions are adhered to and regular feedback given to NEFR officials, in case of speed violations, for necessary action.

v. It is important to afforest railway/linear infrastructure edges, over the longer term, by taking relevant agencies with the RoW (in this case, NEFR) into confidence so that forest regeneration efforts to create natural canopy bridges do not go in vain and natural canopy bridges are eventually established over canopy gaps.

2. Suggested ACB locations at HGS and allied data

Following broad guidelines detailed above, and based on our field surveys at HGS during November 28-December 02, 2022, the following three tables detail seven (07) suitable ACB installation locations along the railway track, post trees' locations and allied details, as well as those of secondary/web trees.

ACB Site no. (from Kothalguri Tea Estate/ western side)	Railway chainage	Site latitude (N)	Site longitude (E)	Main (double-rope) canopy bridge span (m)
1	372/7 - 372/8	26.674144°	94.348467°	36.63
2	372/8 - 372/9	26.674557°	94.349180°	63.40
3	373/0 - 373/1	26.675624°	94.350972°	60.75
4	373/1 - 373/2	26.675829°	94.351315°	54.31
5	373/3 - 373/4	26.676869°	94.353022°	67.69
6	373/4 - 373/5	26.677698°	94.354385°	69.10
7	373/6 - 373/7	26.678849°	94.356263°	41.24
TOTAL				**393.12**

Table 4: Suitable artificial canopy bridge installation sites at the Hollongapar Gibbon Sanctuary

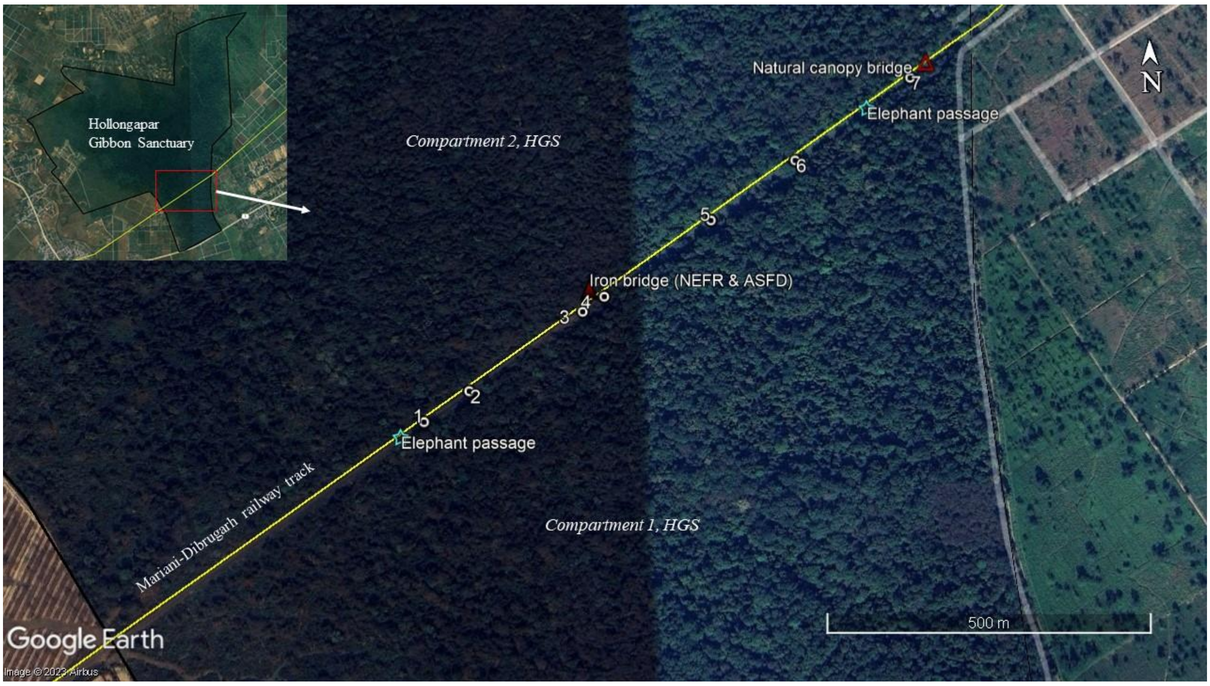

Figure 18: Map depicting seven (07) probable locations for ACB installation at HGS identified in this study; note that locations 4, 7 are near the existing ACB (made of iron) and NCB, respectively

ACB Site No., HGS Compt. No.	Post tree identity (local & scientific names)	Post tree location (lat/ long)	Tree GBH (m)	Total tree height from base (m)	Tree height from rail track level (m)	Tree height (from rail track level) to knot points 1, 2, etc. (m)
1, 1	Sam kothal (*Artocarpus chama*)	N 26.67400, E 94.34850	3.27	26.00	24.25	13.25, 15.75
1, 2	Phul hingori (*Castonopsis indica*)	N 26.67432, E 94.34843	3.65	25.50	23.50	15.0, 16.0
2, 1	Phul hingori (*Castonopsis indica*)	N 26.67438, E 94.34939	3.00	28.00	26.25	16.25, 17.25
2, 2	Phul hingori (*Castonopsis indica*)	N 26.67478, E 94.34893	4.75	28.50	26.50	19.0, 21.0
3, 1	Pan sopa (*Michelia montana*)	N 26.67538, E 94.35110	2.80	28.00	28.00	20.0, 20.0
3, 2	Sam kothal (*Artocarpus chama*)	N 26.675875, E 94.35084	3.35	33.00	31.50	21.5, 22.5, 25.5
4, 1	Sam kothal (*Artocarpus chama*)	N 26.67562, E 94.35147	1.80	25.00	25.00	20.0
4, 2	Sam kothal (*Artocarpus chama*)	N 26.67602, E 94.35116	2.25	34.00	33.00	21.0, 22.0
5, 1	Gonsoroi (*Cinnamomum glanduliferum*)	N 26.67659, E 94.35308	2.00	36.50	35.00	22.5, 23.5
5, 2	Hal (*Terminalia myriocarpa*)	N 26.67719, E 94.35295	3.20	37.50	36.00	21.5, 22.5
6, 1	Pan sopa (*Michelia montana*)	N 26.67734, E 94.35471	3.40	35.50	33.50	14.0, 16.0

ACB Site No., HGS Compt. No.	Post tree identity (local & scientific names)	Post tree location (lat/ long)	Tree GBH (m)	Total tree height from base (m)	Tree height from rail track level (m)	Tree height (from rail track level) to knot points 1, 2, etc. (m)
6, 2	Sam kothal (*Artocarpus chama*)	N 26.67782, E 94.35427	4.10	37.50	36.50	24.0, 25.0
7, 1	Sam kothal (*Artocarpus chama*)	N 26.67863, E 94.35643	2.54	29.00	29.00	22.0, 24.0
7, 2	Mango (*Mangifera indica*)	N 26.67894, E 94.35620	3.00	26.00	26.00	22.0, 24.0

Table 5: Location, identity and other necessary details of 14 'post trees' at the seven probable ACB installation sites along the railway track in HGS (note that scientific names of all trees may not be accurate)

Figure 19: Identified 'post trees' in this study are strong, sturdy and mature individuals with multiple available branching/knot points at appropriate heights; all post trees have been physically marked in the field by a red ribbon tied around their main trunks; experienced field staff Mr. Suchen Borah (left) and Mr. Deben Borah (right) helped the WII research team in tree identification and in general conducting fieldwork at HGS, Assam

ACB Site No.	HGS Compt. No.	Secondary tree name (local)	Secondary tree name (scientific)	Secondary tree location (lat/ long)	Total tree height from base (m)	Dist. from Post tree (m)
1	**1**	Kenglo	*Trewia nudiflora*	N 26.67399, E 94.34870	22.0	19.860
		Ajhar	*Lagerstroemia speciosa*	N 26.67381, E 94.34841	13.0	23.325
		Hollong	*Dipterocarpus macrocarpus*	N 26.67368, E 94.34862	25.0	37.458
	2	Kenglo	*Trewia nudiflora*	N 26.67456, E 94.34841	17.5	25.770
		Lewa	*Engelhardtia spicata*	N 26.67445, E 94.34860	17.5	22.160
		Seleng	*Sapium baccatum*	N 26.67454, E 94.34858	17.5	28.542
2	**1**	Kenglo	*Trewia nudiflora*	N 26.67456, E 94.34951	18.0	22.965
		Ajhar	*Lagerstroemia speciosa*	N 26.67434, E 94.34930	16.0	9.521
		Bandordima	*Dysoxylum sp.*	N 26.67422, E 94.34948	15.0	15.187
	2	Kenglo	*Trewia nudiflora*	N 26.67479, E 94.34905	22.5	12.103
		Kadam	*Neolamarckia cadamba*	N 26.67486, E 94.34906	24.5	15.950
		Ajhar	*Lagerstroemia speciosa*	N 26.67496, E 94.34896	15.0	20.369
3	**1**	Jamuk	*Syzygium cumini*	N 26.67547, E 94.35122	14.0	16.343
		Amari	*Aglaia spectabilis*	N 26.67528, E 94.35120	14.5	14.562
		Phul hingori	*Castanopsis indica*	N 26.67514, E 94.35107	25.5	26.575
	2	Ajhar	*Lagerstroemia speciosa*	N 26.67584, E 94.35070	14.0	13.859
		Ajhar	*Lagerstroemia speciosa*	N 26.67599, E 94.35073	15.5	16.125
		Ajhar	*Lagerstroemia speciosa*	N 26.67604, E 94.35093	17.5	20.001
4	**1**	Sam kothal	*Artocarpus chama*	N 26.67556, E 94.35156	25.0	10.664
		Kenglo	*Trewia nudiflora*	N 26.67552, E 94.35137	24.0	15.152
		Seleng	*Sapium baccatum*	N 26.67575, E 94.35165	25.0	22.605
	2	Bohot	*Artocarpus lacucha*	N 26.67601, E 94.35109	14.5	7.528
		Ajhar	*Lagerstroemia speciosa*	N 26.67614, E 94.35108	18.5	15.442
		Otenga	*Dillenia indica*	N 26.67603, E 94.35125	13.5	8.770

ACB Site No.	HGS Compt. No.	Secondary tree name (local)	Secondary tree name (scientific)	Secondary tree location (lat/ long)	Total tree height from base (m)	Dist. from Post tree (m)
5	**1**	Bandordima	*Dysoxylum sp.*	N 26.67672, E 94.35314	16.0	15.492
		Sam kothal	*Artocarpus chama*	N 26.67647, E 94.35319	36.0	16.782
		Kenglo	*Trewia nudiflora*	N 26.67663, E 94.35289	22.0	19.401
	2	Unidentified	NA	N 26.67735, E 94.35302	17.5	19.028
		Ajhar	*Lagerstroemia speciosa*	N 26.67728, E 94.35280	13.5	18.366
		Tita sopa	*Michelia oblonga*	N 26.67723, E 94.35315	25.5	19.957
6	**1**	Morhal	*Vatica lanceaefolia*	N 26.67719, E 94.35472	17.5	16.104
		Pan sopa	*Michelia montana*	N 26.67745, E 94.35449	24.0	25.539
		Gahori sopa	*Magnolia griffithii*	N 26.67750, E 94.35476	16.5	18.466
	2	Kenglo	*Trewia nudiflora*	N 26.67797, E 94.35414	31.0	20.624
		Jamuk	*Syzygium cumini*	N 26.67808, E 94.35421	26.0	29.412
		Sashi	*Aquilaria agallocha*	N 26.67792, E 94.35442	26.0	18.720
7	**1**	Sam kothal	*Artocarpus chama*	N 26.67853, E 94.35647	27.0	11.798
		Morhal	*Vatica lanceaefolia*	N 26.67863, E 94.35627	17.0	15.736
		Morhal	*Vatica lanceaefolia*	N 26.67845, E 94.35637	20.0	21.610
	2	Borpat	*Ailanthus integrifolia*	N 26.67928, E 94.35602	34.5	41.170
		Ajhar	*Lagerstroemia speciosa*	N 26.67936, E 94.35628	23.5	47.271
		Borpat	*Ailanthus integrifolia*	N 26.67882, E 94.35601	28.0	23.059
TOTAL						**839.371**

Table 6: Location, identity and other necessary details of 42 probable 'secondary/web trees' (three web trees each for 14 post trees) at the seven suitable ACB installation sites in HGS (note that scientific names of all trees may not be accurate)

From field data collected in the Hollongapar Gibbon Sanctuary, the average "post tree" height from the seven suggested ACB sites (total 14 trees) is 30.71 m (range: 25.5-37.5 m). The chosen post trees have an average girth at breast height (GBH) of 3.08 m (range: 1.8-4.75 m) signifying their sturdiness and maturity. The average height (measured from the rail track) at which knot points on post trees (1-3 each, total 28 to choose from) are available is sufficiently high at 19.55

m (range: 13.25-25.0 m), while the average main (double-rope) bridge span over the canopy gap/railway track (post-post tree connections) is 56.16 m (range: 36.63-69.1 m, total length 393.12 m). On an average, a secondary/web tree (total 42, three for each of 14 post trees at the seven sites) is situated 19.98 m (range: 7.528-47.271 m) away from its post tree for which single-rope bridge/connections could be provided (total length 839.371 m), while an average secondary tree's height is 20.63 m (range: 13.0-36.0 m).

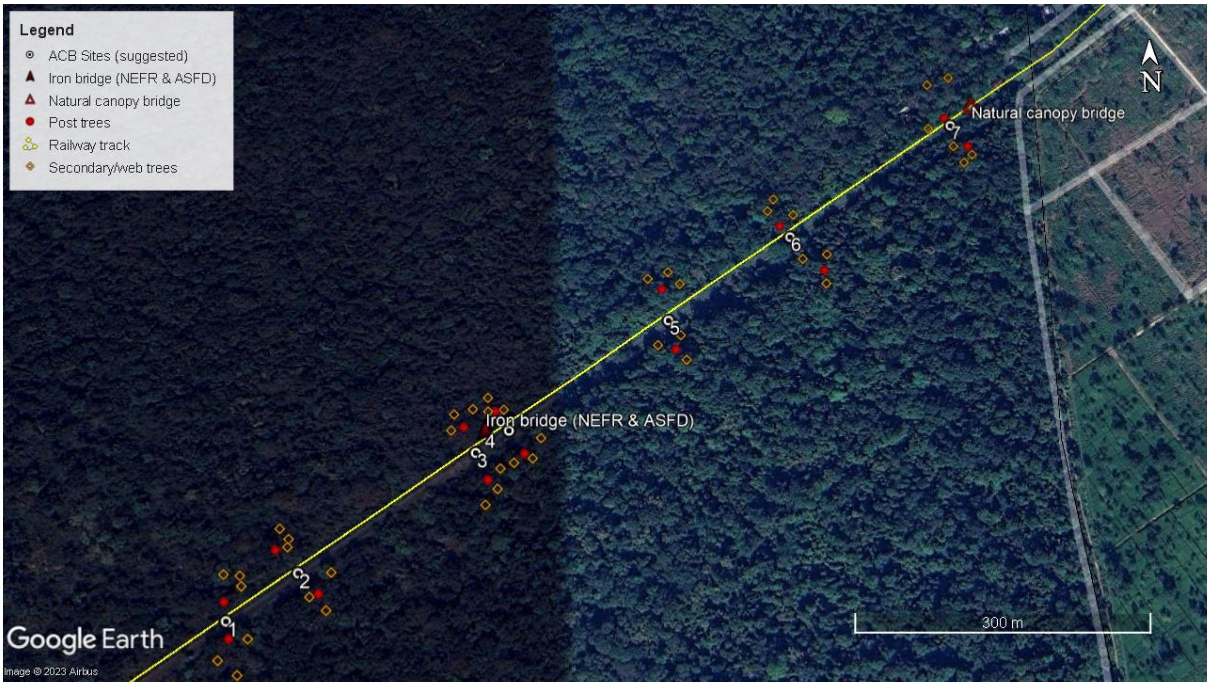

Figure 20: Map showing all post and secondary/web trees at the seven identified locations within HGS where artificial canopy bridges may be installed

IV. CONCLUSION

The state of Assam has been a pioneer in positive conservation action as the people of Assam have demonstrated and conveyed (to their representatives) their resolve to save species from various anthropogenic impacts, even from the brink of extinction (Greater one-horned rhinoceros is a case in point). It is, thus, along expected lines that the Assam Forest Department and the State Government has initiated the task of installing artificial canopy bridges to secure the long-term future of primarily the Hoolock gibbon, but also of other arboreal animals', from the threat imposed by the canopy gap due to the existing railway track.

While the installation of artificial canopy bridges is one of the solutions and an important first step, it is important that other more long-term interventions, with the support of stakeholders such as local communities and Indian Railways, are also carried out, some of which include (but are not limited to):

1. Efforts to establish/ reforest ecological/ wildlife corridors and 'stepping-stone' habitats around Hollongapar Gibbon Sanctuary so that the immense biodiversity value of the Sanctuary is conserved and wildlife has space to occupy and move in the larger forested landscape of the region.

2. The Indian Railways has set a target of becoming a ‘Net Zero’ entity by 2030 through complete electrification of its network. In this respect, work on the electrification of the Dibrugarh-Mariani railway line is currently underway in a phase-wise manner. However, since electrification will impose further costs on HGS’s arboreal wildlife (through the additional danger of being accidentally electrocuted), it is necessary that any such modification is carefully thought through and relevant mitigation and compensation measures implemented.

3. The current single-track broad gauge railway line at HGS has caused a wide canopy gap of 30-40 metres. Any future plan of doubling the track (and possible electrification of the same) passing through the Sanctuary limits will render the installation of artificial canopy bridges useless by further widening the canopy gap (possibly up to 100 metres accounting for distance between the tracks). Since the railway stretch within HGS is relatively small, the Indian Railways must think long-term and demonstrate its conservation vision by exploring all possibilities to reroute the existing line outside HGS (and its ESZ) limits into the adjoining revenue and non-forest land. This will ensure that a balance between ecology and economy is struck, and allow for the necessary doubling and electrification of such a rerouted line (with structural and other mitigation measures, if needed).

4. Since natural canopy bridges is the most effective way of connecting forest canopy gaps, it is necessary that appropriate reforestation activities (including protecting the saplings until they are established) is carried out along both sides of the existing railway track. This is especially urgent along the latter half of the railway track through HGS (towards Kothalguri Tea Estate) where the canopy gap is very wide at present.

5. Establishment of and supporting (through incentives and forward marketing-linkages) small-scale and regulated homestay-based ecotourism activities with its economic benefits directly accruing to members of local communities and towards supporting wildlife conservation and basic village development activities will help firmly establish people as direct stakeholders in the Sanctuary’s and its inhabiting wildlife’s conservation.

As far as the installation of ACB structures within the HGS is concerned, it must be urgently executed with the active involvement of professionals and experts with domain knowledge from the fields of ecology/primatology, engineering, forestry, mountaineering and such other. Representatives of the Indian Railways should also be involved to ensure smooth coordination and ensure their support as well. For this purposes, under the leadership and stewardship of the Assam State Forest Department, a ‘Steering Committee’ may be formed with representation from local conservation organisations such as Aaranyak, Conservation Initiatives and from the WII. Additional representation from Indian Railways/ its consultant organisations (as necessary) and from a reputed mountaineering institute such as the Himalayan Mountaineering Institute, Darjeeling (to provide specific inputs regarding fine-tuning the ACB design outlined in this report, material/equipment procurement and making professional climbers/mountaineers available) will be crucial to the success of this initiative. A well-established post-installation monitoring protocol and associated research activities are a must to document learnings from this initiative for other landscapes, and towards effecting necessary course corrections.

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APPENDIX 1 – DFO (Territorial), Jorhat letter to Director, WII dated 08.08.2022 requesting inputs into designing a canopy bridge over railway line inside Hollongapar Gibbon Sanctuary

(3)

GOVERNMENT OF ASSAM
DEPARTMENT OF ENVIRONMENT & FORESTS
OFFICE OF THE DIVISIONAL FOREST OFFICER
JORHAT DIVISION: JORHAT

Ph: 03762950090 **E-mail: dfo.t.jorhat@gmail.com**

Letter No.FJT/B/Canopy Bridge/34/ 3527 **Date: 08th Aug 2022**

To

The Director,
Wildlife Institute of India,
Dehradun.

Sub: Request for designing canopy bridge over railway line inside Hollongapar Gibbon Sanctuary – reg.

Sir,

With reference to subject cited above, I would like to mention that Hollongapar Gibbon Sanctuary is located in Jorhat Division of Assam state. This is the only sanctuary in India harbouring 7 (seven) primate species and hoolock gibbon (*Hollock hoolock*) is the flagship species of this sanctuary. Hoolock gibbon which is an endangered species as per IUCN category is a frugivorous, arboreal and monogamous primate species.

Inside the Hollongapar Gibbon Sanctuary, a railway line from Mariani to Dibrugarh passes through it. This has resulted in a wide canopy gap, which has divided the sanctuary into 2 (two) parts. This is restricting the movement of the hoolock gibbon and has resulted in isolation of them on either side. This long isolation is restricting the gene flow between the hoolock gibbon families and is also posing threat of inbreeding depression.

In this context, it is proposed to construct a canopy bride across the railway line which will enable the movement of the hoolock gibbons on either side of railway line. Hoolock gibbon being a very shy and arboreal primate, it is required to consider parameters like - animal behaviour, animal safety, materials preferred by the primates for brachiation so on. In this regard, inputs from the wildlife experts are required, so that, a gibbon friendly canopy bridge is built inside the sanctuary.

Since, Wildlife Institute of India, is a premier institute with expertise in diverse wildlife matters, it is hereby kindly requested to help us in designing a canopy bridge, which will be used by the gibbons for locomotion over the canopy gap created by the railway line inside the Hollongapar Gibbon Sanctuary. Your cooperation in this matter is highly solicited.

This is for your kind consideration and necessary action.

Yours truly,

Divisional Forest Officer,
Jorhat Division, Jorhat.

Dean

DWII OFFICE
DIARY NO. 2684
DATE 16/8/2022

Dr. Gopi
Please discuss
We need to communicate
canopy connecting bridges
18/8/22

Page 1 of 2

APPENDIX 1 – DFO (Territorial), Jorhat letter to Director, WII, dated 08.08.2022 requesting inputs into designing a canopy bridge over railway line inside Hollongapar Gibbon Sanctuary

②

Memo No: FJT/A/Canopy Bridge/34/ 2147-49 **08th Aug 2022**

Copy to:

1. The Principal Chief Conservator of Forests & Head of Forest Force, Assam, Aranya Bhavan, Panjabari, Guwahati – 37 for favour of his kind information and necessary action.
2. The Principal Chief Conservator of Forests (Wildlife) & Chief Wildlife Warden, O/o PCCF & HoFF, Assam, Aranya Bhavan, Panjabari, Guwahati – 37 for favour of his kind information and necessary action.
3. The Conservator of Forests, Eastern Assam Circle, Jorhat – 1 for favour of his kind information.

Divisional Forest Officer,
Jorhat Division, Jorhat.

भारतीय वन्यजीव संस्थान
Wildlife Institute of India
(An Autonomous Institute under Ministry of Environment, Forest & Climate Change, Govt. of India)
पत्रपेटी सं0/Post Box No. 18, चन्द्रबनी, देहरादून/Chandrabani, Dehradun - 248001, उत्तराखण्ड, भारत/Uttarakhand, INDIA

Azadi Ka Amrit Mahotsav

WII-EIA/Canopy Bridge/HGS_147 — 04 October 2022

To,

Divisional Forest Officer (Jorhat Territorial Division)
Department of Environment & Forests, Government of Assam
Atilagaon, Jorhat 785001, Assam
Email: dfo.t.jorhat@gmail.com

Sub: Request for designing canopy bridge over railway line inside Hollongapar Gibbon Sanctuary – reg.

Ref: Your letter no. FJT/B/Canopy Bridge/34/3527 dated 08 August 2022

Sir/Madam,

You may already be aware that the only long-term solution towards meaningfully connecting populations and habitats of highly arboreal species such as gibbons, monkeys, lemurs, lorises, civets, squirrels among other mammals fragmented by linear intrusions such as roads, railways, canals etc. is to reforest areas along the said linear gap with fast-growing native trees preferred by the target species/taxa. However, as a short-term and inexpensive conservation measure, constructing well-designed and suitably sited artificial or semi-artificial canopy bridges across linear intrusions at frequent intervals may reduce the barrier effect and help in connecting isolated groups/populations, besides mitigating the risk of accidental collisions and vulnerability to predators during ground movements.

The utility of canopy bridges in this context has been successfully demonstrated for various primate species around the world utilising various designs and materials. In India, canopy bridges made of used fire-hose pipes are facilitating lion-tailed macaque *Macaca silenus* movements and helped reduce their accidental road fatalities in the Valparai plateau of Tamil Nadu. Horizontal ladder bridges made of bamboo and simple/nylon ropes installed in Chakrashila Sanctuary (Assam) and Chinnar Sanctuary (Kerala) over roads are being used by species such as golden langur *Trachypithecus geei*, tufted gray langur *Semnopithecus priam* and grizzled giant squirrel *Ratufa macroura* among others.

All gibbon species are globally threatened, particularly shy, and are exclusively arboreal (usually in the middle canopy), thereby making both the design and construction of artificial canopy bridges a challenging exercise. Moreover, the effectiveness of artificial canopy bridge as a conservation tool for wild gibbons has not been widely experimented, and the results are rarely published. A simple bamboo canopy bridge in the Borajan reserve of Assam demonstrated limited success in the early 2000s for western hoolock gibbons *Hoolock hoolock*, and rope bridges over roads in Thailand have proven useful for lar gibbons *Hylobates lar*. Most recently, pairs of mountaineering-grade ropes tied to sturdy trees were shown to be successful for the critically endangered Hainan gibbons *Nomascus hainanus* in China.

A few pre-requisites towards designing the best-suited canopy bridge for gibbons in Hollongapar Gibbon Sanctuary fragmented by the Mariani-Dibrugarh railway line is the availability and careful perusal of data on animal crossings/sightings to site the intervention at most suitable location(s), local consultative meetings with all stakeholders (including Indian Railways) and gibbon experts/conservationists along with a joint site-evaluation visit. The following conservative budget is hence proposed for a site-evaluation visit tentatively during November 10-20, 2022, subsequent to which the most appropriate and gibbon-friendly canopy bridge design(s) could be finalised and later executed in the field on an experimental basis with detailed follow-up studies.

Travel to field site and back (Dehradun-Jorhat-Dehradun) via air/rail – INR 75,000/-
Local travel & Accommodation (10 days/nights) – INR 1,00,000/-
Meetings & Discussions with stakeholders and primate experts to deliberate and finalise canopy bridge design – INR 10,000/-
Contingency & Miscellaneous costs – INR 15,000/-
Professional faculty charges @ INR 5,000/day for 10 days – INR 50,000/-

ई.पी.ए.बी.एक्स/EPABX : +91-135-2640114, 2640115, 2646100; फैक्स/ Fax : 0135-2640117 | ई-मेल/Email: wii@wii.gov.in वेब/ Website www.wii.gov.in Twitter: @wiiofficial1

Hence, a total of **INR Two lakh fifty thousand only (Rs. 2,50,000/-)** is kindly sought from the Department of Environment and Forests, Government of Assam to facilitate the field visit along with necessary logistical and accommodation support, and all other assistance as required. During the field visit, it is also requested that WII be kindly provided with all the required data from the concerned Division such as geographical coordinates of animal movements/primate crossing spots, divisional boundaries (including beat and range), ESZ boundaries, PFs and RFs in the surrounding areas, incidents of accidental animal fatalities (road/rail) etc. Soft copies of Divisional Working Plans and Sanctuary Management Plan, ESZ Notification etc. pertaining to the Gibbon Sanctuary and adjoining forested areas will also be very useful.

Yours sincerely,

(Dr. Yadvendradev V. Jhala)
Dean, FWS

Copy to:

1. **Principal Chief Conservator of Forests (Wildlife) & Chief Wild Life Warden, Govt. of Assam, Panjabari Road, Batahguli, Guwahati 781037. Email: pccf.wl.assam@gmail.com**

2. **Dr. G. V. Gopi, Scientist 'E' & Head, Department of Endangered Species Management & Nodal Officer, EIA Cell, WII. Email: gopigv@wii.gov.in, eia@wii.gov.in**

Contact details:

Nodal Officer, EIA Cell
Wildlife Institute of India
Dehradun – 248001
Uttarakhand, India
Email: eia@wii.gov.in