Connecting Fragments and Gibbons After a Century of Separation: A Natural Canopy Bridge at the Hollongapar Gibbon Wildlife Sanctuary, Assam, India

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Abstract: Habitat fragmentation resulting from linear infrastructure such as pipelines, roads or railways has emerged as one of the severest threats for wildlife globally. Among the many primate species affected by fragmented habitats, the loss of canopy connectivity in a fragmented landscape is especially detrimental to highly arboreal, canopy dwelling species, such as gibbons. The Hollongapar Gibbon Wildlife Sanctuary in Assam, India, a stronghold for the Endangered western hoolock gibbon (*Hoolock hoolock*), is bifurcated by a railway track constructed by the British in 1887. It is a barrier to the movement of wildlife in the sanctuary and the gibbons there have, since then, been isolated on either side of the track. To bridge this gap and facilitate unrestricted movement of gibbons, since 2006 we have been developing a natural canopy bridge across the railway line through coordinated tree planting, using saplings of various indigenous species on both side of the railway track along a 1-km stretch. The species selected were known to be preferred as food and sleeping trees by the gibbons. In 2019, a natural bridge was formed in one location by joining branches of the trees on either of the track. Gibbons and other arboreal species such as the capped langur, rhesus macaque and squirrels have been observed to use this canopy bridge. This natural canopy bridge has given a new lease on life to the wildlife community of the sanctuary, especially the gibbons. While the data presented here provide preliminary documentation of the natural canopy bridge and its use, further research is planned to ascertain the level of its benefit for the gibbons and other arboreal mammal species.We strongly encourage the inclusion of natural canopy bridges in the development programs involving linear infrastructure since these bridges are cost effective and extremely valuable in increasing forest connectivity.

Key words: Hoolock gibbon, fragmentation, isolation, mitigation, railway tracks, Assam, India

Introduction

Habitat fragmentation is a severe threat to biological diversity and is considered by some to be a primary cause of the present extinction crisis (Umapathy 2020). Indeed, anthropogenic habitat fragmentation is increasing at an alarming rate throughout the world (Seto *et al*. 2012) along with a simultaneous increase in the construction of roads and other linear infrastructure elements (Reed *et al*. 1996; Santos *et al*. 2002; Oliveira *et al*. 2007; Swenson *et al*. 2011; Laurance 2018). Without increased efforts to slow the rate of fragmentation and reconnect fragments, the biodiversity crisis will continue.

Of the 20 known species of gibbons, just one—namely, the western hoolock gibbon, *Hoolock hoolock* (Harlan, 1834), occurs in India. For a time, it was thought that a second species, the eastern hoolock gibbon, *Hoolock leuconedys* (Groves, 1967), was also present in the Mishmi Hills, between the Dibang and Nao Dehing rivers in Arunachal Pradesh (Chetry *et al*. 2008, 2012). A phylogenetic analysis by Trivedi *et al.* (2021) refuted this. Although genetically similar (Trivedi *et al.* 2021), the gibbons of the Mishmi Hills are distinct in their appearance, leading Choudhury (2013, 2022) to describe them as a subspecies of the western hoolock, *Hoolock hoolock mishmiensis*. Only seven states in the northeast region of India—Assam, Arunachal Pradesh, Tripura, Manipur, Meghalaya, Nagaland and Mizoram—support the entire gibbon population in the country, limited to the southern bank of the Dibang-Brahmaputra River system.

The western hoolock gibbon is listed as Endangered on the IUCN Red List of Threatened Species (Brockelman *et al*. 2019), and the Indian Wildlife (Protection) Act of 1972 has it classified as a schedule-I species. Several studies carried out in India have identified habitat loss, habitat fragmentation, and hunting as the greatest threats for this species throughout their entire distribution in India (Chetry *et al*. 2007).

Given that hoolock gibbons are exclusively arboreal and do not cross open spaces on the ground, habitat fragmentation presents a particular concern for their conservation. Efforts to connect fragmented habitats via artificial canopy bridges (ACB) in India (Das *et al.* 2009) and elsewhere have increased in recent years and offer a potentially viable solution to enhance wildlife movement and habitat access (Chan *et al.* 2020). Here we report on a program to establish a natural canopy bridge (NCB) and its subsequent use by western hoolock gibbons in the Hollongapar Gibbon Wildlife Sanctuary in Assam, India.

The Hollongapar Gibbon Wildlife Sanctuary

The Hollongapar Gibbon Wildlife Sanctuary (HGWLS) was named after the hoolock gibbon and is the only protected area in India named after a primate. It is the first protected area in the country where the western hoolock gibbon is the target species for conservation. The sanctuary consists of an isolated forest of 2,098 ha along the south bank of the Brahmaputra River in the district of Jorhat, Assam (94°20' to 94°25'W and 26°40' to 26°45'S) (Fig. 1). The HGWLS supports a population of 125 western hoolock gibbons, and is considered by the Assam Forest Department to be an important stronghold for this species. The sanctuary is also home to six other primates: the capped langur (*Trachypithecus pileatus*), the stump-tailed macaque (*Macaca arctoides*), the northern pigtailed macaque (*M. leonina)*, the Assamese macaque (*M. assamensis*), the rhesus macaque (*M. mulatta*), and the Bengal slow loris (*Nycticebus bengalensis*), and is the the area with the highest primate diversity in India (Srivastava *et al*. 2001; Chetry *et al*. 2007).

The HGWLS was previously known as the Hollongapar Reserve Forest (Government notification No.8, August 1881). At the time, the area was an integral part of the

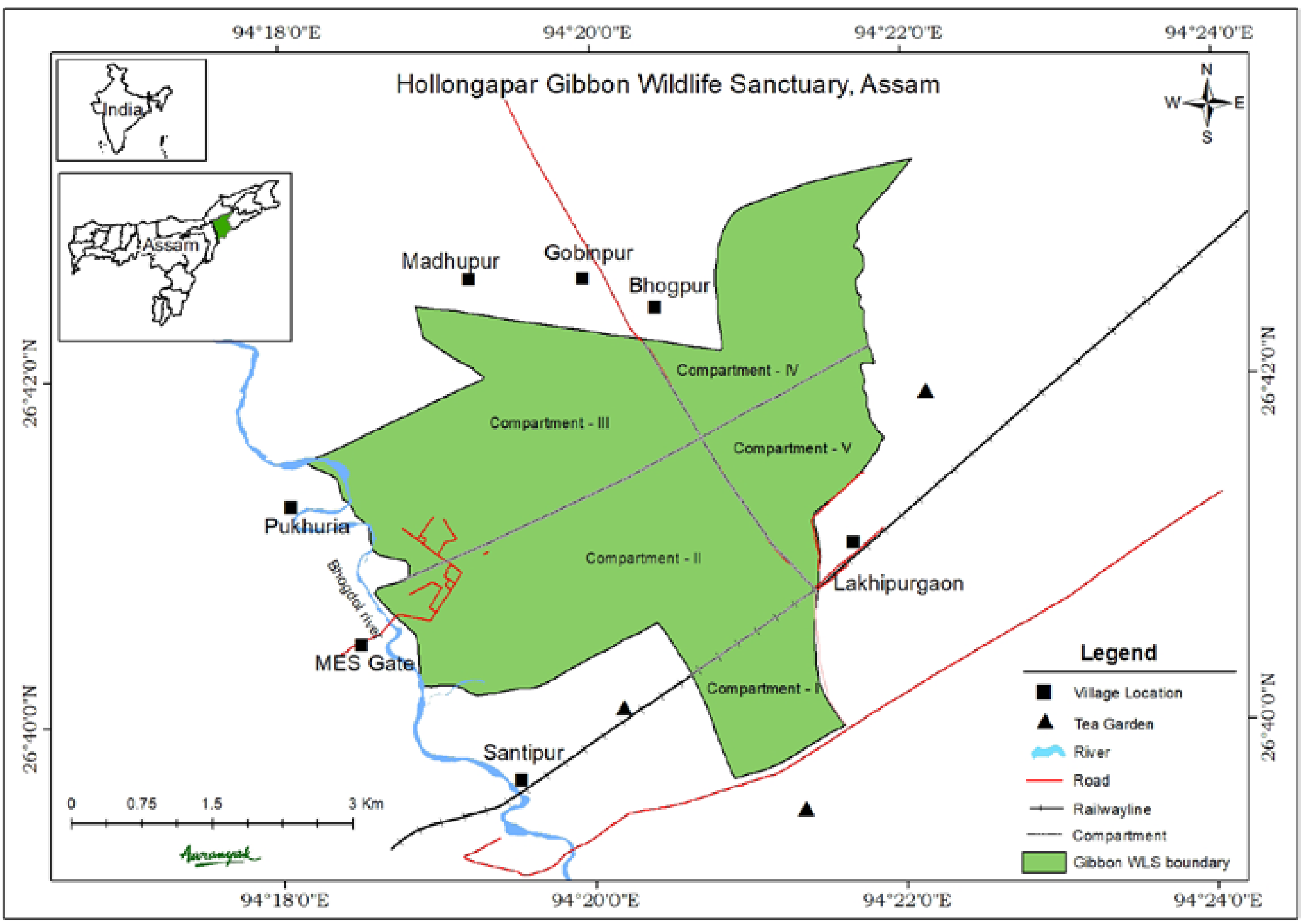

Figure 1. The Hollongapar Gibbon Wildlife Sanctuary, Assam, India.

foothill forests of the Patkai range. With the establishment of tea plantations from 1880–1920, the forest became fragmented into reserve forests such as Dessoi, Dessoi Valley, and Tiru Hill. The original Hollongapar Reserve Forest covered an area of only 206 ha but, following the subsequent inclusion of additional forest, by the year 1997 the total area had increased to 2,098.62 ha, and it was given protected status as the Gibbon Wildlife Sanctuary by the Government of Assam (Notification no. FRS/37/97/13, dated 30 July 1997). In 2004, the Government of Assam changed the name to the Hollongapar Gibbon Wildlife Sanctuary.

Surrounded by human habitations and tea plantations on almost all sides, the sanctuary of lowland forest (altitude 100–120 above sea level) with numerous small streams, is now essentially a "forest island.". Its boundaries extend to the Dissoi Valley Reserve Forest, the Dissoi Reserve Forest, and the Tiru Hill Reserve Forest. It was once contiguous with all three reserve forests, but the contiguity was lost due to the establishment of tea plantations.

The forest type in the sanctuary is known as the Assam Plains Alluvial Semi-Evergreen forest with patches of Wet Evergreen forest (Chetry 2002). The principal trees, forming the top canopy, are *Amoora wallichi* (Meliaceae), *Anthocephalus cadamba* (Rubiaceae), *Arctocarpus chama* (Moraceae), *Canarium resiniferum* (Burseraceae), *Castopnopsis indica* (Fagaceae), *Dipterocarpus retusus* (Dipterocarpaceae), *Duabanga sonneratioides* (Lythraceae), *Lagerstroemia floreginae* (Lythraceae), *Mansonia dipikae* (Malvaceae), and *Sapium baccatum* (Euphorbiaceae). The middle storey is typically composed of *Aquilaria agolacha* (Thymelaeaceae), *Biscofia* sp. (Phyllanthaceae), *Mangifera javanica* (Anacardiaceae), *Dilena indica* (Dilleniaceae), *Elaeocarpus ganitrus* (Elaeocarpaceae), *Ficus glomeruta* (Moraceae), *Mesua ferrea* (Calophyllaceae), and *Vatica lanceifolia* (Dipterocarpaceae). The lower storey is composed of three non-timber species viz. *Bambusa pallida* (Poaceae), *Calamus* spp. (Arecaceae), and *Pseudostachym polymorphum* (Bambuseae). The undergrowth consists of species of such genera as *Clerodendron* (Lamiaceae), *Commelina* (Commelinaceae), *Eupatorium* (Asteraceae), and *Mikenia scandens* (Asteraceae) (Chetry 2002).

The sanctuary also supports a broad diversity of vertebrate and invertebrate species. More than 200 species of butterflies (Neog 2015) and 95 species of spiders (Kalita 2013) are found in the sanctuary, along with as many as 250 species of birds, including the white-winged wood duck, *Cairina scutulata*, the state bird of Assam, and 41 mammal species (Chetry *et al*. 2001).

Fragmentation

As noted above, the sanctuary is surrounded by tea plantations and human habitation, which often leads to human-wildlife conflict (for example, with elephants, leopards, and monkeys) when animals venture beyond the sanctuary boundary. Within the sanctuary, there has been another long-standing concern due to the railway and the resulting fragmentation of the forest that took place more than 130 years ago.

In 1887, the construction of a railway line cut the sanctuary into two unequal forest fragments or compartments (i.e., Compartment I and Compartment II, see Fig. 1). The railway line is a constant threat—frequent train strikes killing elephants, capped langurs, pythons, for example—and has acted as a barrier to the movement of wildlife in the sanctuary for more than 130 years, and, in particular, has prevented gibbon groups from moving between the two compartments.

Creation of a Natural Canopy Bridge

After more than a century of fragmentation of the railway track passing through the sanctuary, Aaranyak, a scientific and industrial research organization under the leadership of Dilip Chetry, came up with a long-term plan to reconnect the fragmented forest compartments via the creation of natural canopy bridges over the railway tracks. Known as the Hoolock Gibbon Conservation Program, the plan involved a series of tree plantation drives along a 1-km stretch of the railway line. In 2006, with the help of the local community and the Assam Forest Department staff (especially staff of the Melleng Beat office), and with the permission of the railway company, more than 3,000 saplings were planted on either side of the railway track at a distance of 4 m from the track (Fig. 2). The saplings consisted of 71 species known to serve as food sources and sleeping trees for the gibbons. All the saplings were supplied by the Melleng Forest Beat office under the Jorhat Forest Division. Over time, as the trees matured, it was hoped that one or more natural canopy bridges would form, thus providing an opportunity for gibbons to travel between the forest compartments.

Data Collection

Observations of the use of the natural canopy bridge (94°21'23.10"W, 26°40'44.34"S) by gibbons and other wildlife were conducted opportunistically from 2019 through 2021. Observations were recorded by local Forest Department staff stationed at the sanctuary and the research team members.

Results

In 2019, 13 years after the tree planting drive, branches of three trees on either side of the railway track grew to form overlapping branches at their upper canopy thus creating a long-awaited natural canopy bridge (Fig. 3) that was used by gibbons and other arboreal species. Four other NCBs are near completion at the following coordinates: (i) 94°21'21.24"W, 26°40'43.02"S; (ii) 94°21'18.84"W, 26°40'42.06"S; (iii) 94°21'15.00"W, 26°40'39.36"S; and (iv) 94°21'13.74"W, 26°40'37.32"S (Fig. 3). The original NCB consists of one tree on the southeast side of the tracks known as "Jori," *Ficus benjamina* (Moraceae) with a height of 15.2 m and a girth of 96.5 cm at breast height (GBH) and two trees on the northwest side of the tracks, which include a

"Belkor," *Tetrameles nudiflora* (Tetramelaceae), with a height of 14.9 m and a GBH of 91.4 cm, and a "Borpat," *Ailanthus integrifolia* (Simaroubaceae) tree with a height of 12.2 m and a GBH of 91.4 cm (Figs. 4 and 5). During the past 13 years (since the 2006 planting up to the beginning of the study period), a number of the planted trees did not survive, and some were removed by the railway company due to the risk of their falling across the tracks.

Since the formation of the NCB in 2019, six gibbon crossings have been documented involving 1 to 4 gibbons per crossing (Table 1). The gibbons were observed to use the NCB while moving from forest compartment I to II and from compartment II to I. The number of NCB crossings is likely higher since the observations of crossings were opportunistic.

The first reported observation of a gibbon using the NBC was on 20th October 2019 at 8:15 am (reported by Mr. Rupak Bhuyan, forest beat officer at the HGWLS). It was an adult male crossing the NCB from compartment II to compartment I (Table 1).

In addition to the observed gibbon crossings, forest department staff have documented both capped langurs and rhesus macaques using the NCB (Table 1). The staff also observed squirrels using the NCB on a regular basis.

As reported above and indicated on the map (Fig. 3), there are four other locations along the railway track (in close proximity to the current NCB), where the trees are close to forming additional NCBs (i. 94°21'21.24"W,26°40'43.02"S; ii. 94°21'18.84"W,26°40'42.06"S; iii. 94°21'15.00"E, 26°40'39.36"S; iv. 94°21'13.74"W,26°40'37.32"S). When these additional NCBs become functional, they will help provide great NCB options for the gibbons and other wildlife as well as "backups" should something happen to the original NCB.

Discussion

As reported in numerous studies (Fischer and Lindenmayer 2007; Didham 2010; Estrada *et al*. 2017; Haddad *et al*. 2015; Laurance *et al*. 2018; Rogan and Lancher 2018) habitat loss and habitat fragmentation are the two principal threats to terrestrial biodiversity and ecosystems.

Although of course enhancing human mobility and communication, roads and railways have been identified as a potential threat for numerous primates in many areas

Figure 2. "Plantation Programme: Food & Canopy Bridge for Gibbons" in the Hoolock Gibbon Wildlife Sanctuary during 2006. Planting of the trees along the railway track was conducted with the assistance of the local community and the Hoolock Gibbon Conservation Training Trainees. Photographs by D. Chetry, April, 2006.

(Kumara *et al*. 2000; Chhangani 2004; Baskaran and Boominathan 2010; Pragatheesh 2011). Very often, these forms of infrastructure lead to long-term forest fragmentation and, because of an aversion to using the ground, especially arboreal mammals lose access to resources on the other side of the road/track. The impact of linear infrastructure in blocking the movement arboreal species can be observed in many areas (Donaldson and Cunneyworth 2015). Linear barriers such as roads, railway tracks, pipelines, and power line corridors can block the movement of canopy specialists (Wilson 2000; Wilson *et al*. 2008). In extreme cases, the creation of isolated patches can result in the interruption of wildlife movements between local populations (Valladares-Padua *et al*. 1995).

The railway line constructed in 1887 resulted in the fragmentation of the HGWLS, acting as a form of physical barrier for many arboreal mammals especially for the highly arboreal hoolock gibbons, which are true canopy specialists and rarely go down to the ground. The railway line in the HGWLS also created a potential death trap for the wildlife of the sanctuary.

Many wildlife species in the sanctuary are routinely killed by passing trains. Eleven elephants were killed by the trains, two elephants in 2011, one elephant in 2012, two elephants in 2014, two elephants in 2018, one elephant in 2021 and three elephants in 2022 (Deben Dutta and Tarun Das, pers. comm.). Roadkill of forest dwelling mammals is also a common phenomenon elsewhere (Kanowski *et al*. 2001; Collins and Kays 2011; Medrano-Vizcaino *et al.* 2022)

Further, habitat fragmentation increases the probability of extinction due to demographic, environmental, and genetic forces by creating small and isolated subpopulations (Frankham *et al.* 2004). Because of these cascading effects, reducing the impacts of some forms of linear infrastructure such as roads on arboreal wildlife is challenging (Maria *et al.* 2022). Previously, the hazards for the wildlife presented by the railway line passing through the HGWLS, particularly for the gibbons, was not recognized or appreciated. Since 2006, the railway line was identified as a significant threat for gibbons and the need for bridging this gap became a high priority (Chetry 2006).

Artificial canopy bridges (ACBs) are often preferred over NCBs to restore lost forest connectivity (Thurber

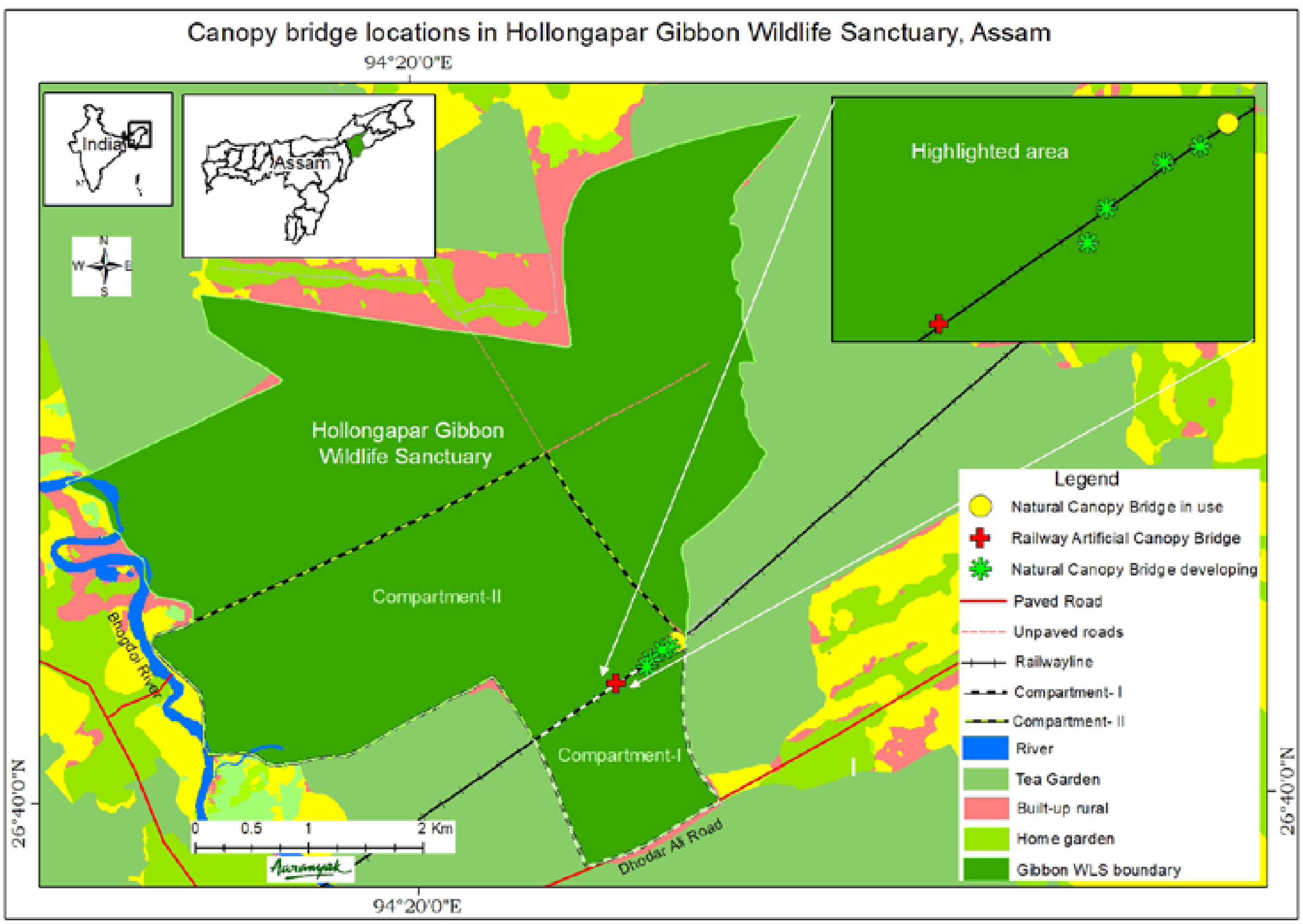

Figure 3. Location of the Natural Canopy Bridge in the Hoolock Gibbon Wildlife Sanctuary connecting forest Compartments I and II.

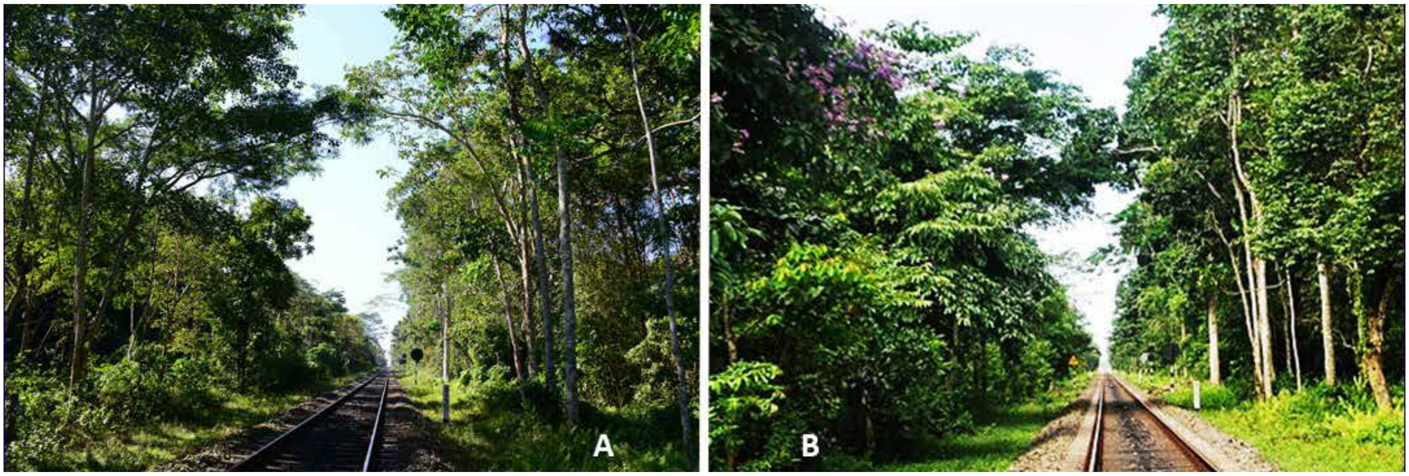

Figure 4. The Natural Canopy Bridge finally connects forest Compartments I and II in the Hoolock Gibbon Wildlife Sanctuary in 2019 (image A, photograph by R. C. Kyes, December 2019) and continuing to grow (image B, photograph by D. Chetry, April 2021).

Figure 5. Train passing under the Natural Canopy Bridge in the Hoolock Gibbon Wildlife Sanctuary. Photograph by D. Chetry, April 2021).

et al. 2016). The architecture and building materials of ACBs vary for different animals (for example, Goosem *et al*. 2005; Lokschin *et al*. 2007; Goldingay *et al*. 2013; Teixeira *et al*. 2013). Some of the most common building materials for ACBs include wooden poles (Valladares-Padua *et al*. 1995; Garcia *et al.* 2022), plastic coated steel cables (Weston *et al*. 2011; Thurber *et al*. 2016), and single rope or bamboo (Das *et al*. 2009; Lindshield, 2016; Narváez Rivera *et al*. 2016; Garcia *et al.* 2022). Das *et al*. (2005, 2009) constructed an experimental temporary bridge using bamboo poles in the Borajan, a part of Bherjan-Borajan-Podumoni Wildlife Sanctuary, to facilitate the movement of gibbons across the canopy gaps. Bamboo poles have been successfully used for lion-tailed macaques (*Macaca silenus*) in the Indira Gandhi Wildlife Sanctuary, Pollachi, Tamil Nadu, India (Chakraborty and Gupta, 2005). Balbuena *et al*. (2019) highlighted the use of both NCBs and semi-artificial canopy bridges (SACB) as a mitigating measure to

Table 1. Observations of gibbons and other primate crossing the Natural Canopy Bridge.

Observation	Date	Direction of Crossing	Species	No. Individuals
1	20/10/2019	Compartment II to I	Western hoolock gibbon (*Hoolock hoolock*)	1
2	30/12/2020	Compartment I to II	Western hoolock gibbon (*Hoolock hoolock*)	2
3	25/2/2021	Compartment I to II	Western hoolock gibbon (*Hoolock hoolock*)	1
4	26/2/2021	Compartment II to I	Western hoolock gibbon (*Hoolock hoolock*)	1
5	30/4/2021	Compartment I to II	Western hoolock gibbon (*Hoolock hoolock*)	4
6	30/4/2021	Compartment II to I	Capped langur (*Trachypithecus pileatus*)	6
7	5/5/2021	Compartment I to II	Western hoolock gibbon (*Hoolock hoolock*)	1
8	5/5/2021	Compartment II to I	Rhesus macaque (*Macaca mulatta*)	3

Figure 6. Artificial Canopy Bridge constructed by railway company in the Hoolock Gibbon Wildlife Sanctuary in 2015. This photograph is looking east, back toward the location of the growing Natural Canopy Bridge. Note that the trees have not yet created the bridge across the tracks. Photograph by R.C. Kyes, November 2015).

bridge the canopy gaps across a gas pipeline in Amazonia. In 2015, at the HGWLS, the Northeast Frontier Railway authority and Assam Forest Department tried to bridge the gap over the tracks by constructing an ACB made of iron (located at: 94°21'3.74"W, 26°40'32.56"S) (Fig. 6). Despite their good intentions, this effort appears to be unsuccessful as no gibbons as well as other primates and arboreal species have been observed to use the bridge to date. This ACB still exists as an unused structure.

Conversely, the current natural canopy bridge developed connecting the branches of trees on either side of the railway line is used by gibbons, capped langurs and squirrels. From our experience, it is evident that it takes quite a long time to develop a suitable NCB. It is more cost effective, however, than an ACB, and has the added advantage of the potential for reforestation and the provision of feeding trees. An NCB developed as a component of the existing forest system increases the likelihood of use by the animals. In the same setting, we have found that an ACB may require a prolonged period of habituation for animal use, if used at all (Saralamba *et al*. 2022). The current study clearly shows that if maintained properly, the NCB can function as a permanent structure for bridging gaps for threatened wildlife and connecting fragments for years to come.

At present, our preliminary observations confirm the use of the NCB by gibbons, capped langur, rhesus macaque and squirrels. Clearly, a more systematic study, involving long-term monitoring, is needed to document the frequency of use by the gibbons as well as other animal species (for example, Gregory *et al.* 2017). We are planning to mount permanent camera traps at the site that will facilitate 24-hour monitoring of the NCB and its use. A long-term study is needed to evaluate the genetic and demographic issue of the two subpopulations of the compartments to verify the effectiveness of the NCB regarding reestablishment of functional connectivity and the sustainability of population. The initial success of this natural canopy bridge provides a model that we can follow in developing additional NCB projects in vulnerable fragmented forests with isolated groups of arboreal primates.

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Statement of Ethics

This study was purely observational and did not involve the collection of any human or animal samples. It was conducted in collaboration with and the approval of the Assam Forest Department, especially the Mariani Range.

Author Contributions

D. C. conceived the study and initiated the reforestation program. D. C., R. C, R. B. and R. C. K. monitored the natural canopy bridge growth, and D.C. and R. B. monitored animal use. D. C., R. C., A. K. D., R. B., and R. C. K. participated in the writing of the article.

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