Photo: In Africa, the projected annual cost of infrastructure is around $93 billion. Highway construction between Port-Gentil and Omboué, Gabon. © Julie Sherman

CHAPTER 3

Deforestation Along Roads: Monitoring Threats to Ape Habitat

Introduction

The International Energy Agency predicts that governments and development agencies will invest more than US$33 trillion to build 25 million km of new paved roads through 2050, a 60% increase over levels in 2010. Nearly 90% of new roadway infrastructure is expected to be built in developing nations (Dulac, 2013). The Asian Development Bank estimates that climate-adjusted infrastructure "investment needs" from 2016 to 2030 will reach about US$16 trillion in East Asia and US$3 trillion in Southeast Asia (ADB, 2017, p. 43). Transportation, the second largest sector, accounts for 32% of expected climate-adjusted infrastructure investments in Asia over the same period. In Africa, the projected annual cost of infrastructure is around US$93 billion, about a third of which is for maintenance, leading to US$1.4 trillion in expenditures over the next 15 years (AfDB, 2011a, p. 28).

The chronic failure of governments to avoid degrading critical wildlife habitat when planning and building infrastructure suggests that this massive investment in transportation networks will have devastating effects on remaining forests (Quintero *et al.*, 2010).

More than other types of infrastructure, roads facilitate forest access that enables logging, settlement, hunting and other resource extraction, beyond direct damage to ecosystems (Trombulak and Frissell, 2000). In fact, many road networks in forested areas in the tropics are sited explicitly to extract natural resources (Nellemann and Newton, 2002). By providing access to forested areas, roads also catalyze various indirect disturbances to remaining habitat —including charcoal production and overhunting—that imperil apes and other arboreal mammals (Coffin, 2007; Wilkie *et al.*, 2000). Greater contact between apes and humans also facilitates the spread of disease between them (Köndgen *et al.*, 2008; Leroy *et al.*, 2004).

The World Bank proposed the concept of "smart green infrastructure" to minimize harm to tigers and their habitat, which are facing a similar crisis (Quintero *et al.*, 2010). The tenets of the Bank's mitigation hierarchy—avoidance, minimization, restoration and offsetting of negative effects—could be applied to reduce the damage caused to ape habitat by infrastructure development (see Table 3.3 and Chapter 4, p. 119). The specializations of many forest-dependent species, including most apes, to the forest environment's stable, moist, shaded conditions and complex architecture make them particularly vulnerable to the damage associated with roads (Laurance, Goosem and Laurance, 2009; Pohlman, Turton and Goosem, 2009; see Chapter 2). Of particular importance to apes, then, is determining whether "greener" infrastructure development can help limit the secondary clearing and resource extraction associated with roads built through forest.

In considering the role of roads in the deforestation of ape habitat, this chapter presents four original case studies and draws on the authors' extensive experience in monitoring forest cover loss, placing particular emphasis on recent technological developments that have allowed for unprecedented access to high-resolution satellite imagery. The research conducted for this chapter reveals the following key findings:

- The construction of new roads in intact forest landscapes is frequently followed by major episodes of deforestation, leading to negative consequences for forest-dependent species such as apes. Deforestation occurs in forest along roads regardless of the protection status of the surrounding area.
- Three case studies presented in this chapter show that drivers of deforestation vary by location, but that road construction is consistently associated with a spike in forest loss, followed by elevated deforestation rates and a progression of forest loss outward from the road over time.
- In the case studies, illegal logging and smallholder agriculture occurred in small clearings close to roads. These activities are more strongly associated with incremental expansion outward from the road and the growth of settlement enclaves than the more organized, and often legal, conversion of larger patches of forest to plantation.
- Planning to avoid critical areas, regular monitoring of forest status and additional conservation action are needed to reduce the negative effects of roads on wildlife habitat. Simple but powerful

approaches to detecting and measuring forest loss can help resource managers monitor the construction and land use change associated with legal roads and halt the building of illegal road clearings in contiguous forest tracts.

- Road design must address the access provided to natural areas by roads that cannot be rerouted. Even if a road does not hinder the movement of apes, the associated conversion of formerly inaccessible forest to other land uses can decimate resident ape populations, as has been the case for western Tanzania's chimpanzee populations.
- In Peru's primate-rich Amazon forests, deforestation tracking combines weekly alerts of tree cover loss with verification using high-resolution satellite imagery. This useful model for combating illegal road building and associated land clearing activities could easily be adapted to ape habitats.

Proposed New Approaches to Road Monitoring

Roads and other forms of transportation infrastructure can bring rural communities much-needed social and economic benefits, including access to markets and resources; however, this is not always the case (see Chapter 2, p. 60). Ideally, these arteries connect people to markets and resources while avoiding primary forest, sensitive habitats, animal dispersal and migratory routes, and unique natural communities. However, recent road planning often fails to consider these factors. Without proper planning and post-construction monitoring, roads can incur tremendous costs of time and money while devastating the surrounding environment and creating public health issues (Clements, 2013; Laurance *et al.*, 2009; see Chapter 1).

This chapter provides three examples of road construction projects that have affected

Photo: More than other types of infrastructure, roads facilitate forest access that enables logging, settlement, hunting and other resource extraction. © HUTAN–Kinabatangan Orang-utan Conservation Project

surrounding ape forest habitat. A fourth case study was conducted outside an ape range but is relevant to monitoring primate habitat; it shows how new data and tools available to the ape conservation community can help detect, monitor, predict and minimize forest loss. Specifically, satellite imagery and associated spatial data analysis tools now permit resource managers to more effectively monitor changes in canopy cover of ape habitat surrounding infrastructure and other developments (see Annex II). This approach has already been used to assess remaining habitat for tigers and to influence landscape-level planning to ensure their survival (see Box 3.1). It can be applied to ape habitat in the same way.

Data and maps of expected tree cover loss associated with proposed infrastructure routes can inform road siting and suggest preventive actions to minimize deforestation, assuming that high-level decisions incorporate environmental information. These tools can also help to reduce damage from roadways by:

- estimating potential impact within the area surrounding a proposed road;
- detecting tree cover loss along a new roadway before it expands;

BOX 3.1

Applying Lessons from Tiger Habitat Analysis to Ape Habitat Monitoring and Conservation

Like apes, tigers need large areas to survive. But loss of habitat, combined with overhunting of both tigers and their prey, has diminished the global wild population to fewer than 3,500 individuals (Joshi *et al*., 2016). Nevertheless, sufficient forested tiger habitat still remains across the species' range to bring the tiger back from the brink of extinction.

A recent assessment of critical tiger habitat utilized a new satellite-based monitoring system to analyze 14 years of forest loss data within the 76 landscapes that have been prioritized for the conservation of wild tigers (Joshi *et al*., 2016). Published in 2016, the study identifies enough forest habitat within tigers' geographic range to achieve the international commitment of doubling the wild tiger population by 2022—an initiative known as Tx2 (World Bank, 2016b)—with additional conservation investment.

The researchers systematically examined forest cover change across globally recognized tiger conservation landscapes (TCLs), which have a median area of 2,904 km^2 (290,400 hectares (ha)) (Joshi *et al*., 2016; Wikramanayake *et al*., 2011). They used high- and medium-resolution satellite data provided by Global Forest Watch and Google Earth Engine, along with analysis from the University of Maryland (GFW, 2014; Google Earth Engine Team, n.d.).

The open-access GFW platform provides tools that forest managers and others can use to measure and monitor critical habitats, analyze risk and prioritize conservation efforts. The research team used annually updated GFW tree cover data at a resolution of 30 m × 30 m to detect and locate forest loss.

The researchers estimate that forest clearing between 2000 and 2014—an area equivalent to nearly 80,000 km^2 (8 million ha) or 7.7% of the tigers' remaining habitat—resulted in the loss of habitat that could have supported an estimated 400 tigers, more than one-tenth of the global population (Walston *et al*., 2010). Across the 76 TCLs, forest loss was actually much lower than expected, given the region's rapid economic growth and high population densities.

Loss was also unevenly distributed: 98% of tiger forest habitat loss across the 29 most critical TCLs for increasing tiger populations occurred within just ten of these landscapes, primarily in Indonesia and Malaysia, where oil palm plantations are driving deforestation. Many of these TCLs, especially in Sumatra, are also home to critically important ape populations (IUCN, 2016c; see Chapter 7).

The results of the habitat assessment allow scientists and tiger range authorities to improve their understanding of the spatial distribution of intact forest, tree cover loss and human development within the TCLs so that conservation resources can be applied where they are most needed to avert further damage.

In Indonesia, more than 4,000 km^2 (400,000 ha) of unbroken forest expanses in TCLs have been allocated for oil palm concessions. Conversion of these forests would fragment forest corridors and deplete habitat in protected areas. If this faster rate of habitat loss is to be addressed, conservation investment in these TCLs will need to be particularly intensive and targeted at commodity production practices.

The tiger habitat assessment introduces tools that, had they been part of the toolkit of forest and wildlife managers, could have helped detect and address forest change even at the landscape level. Forest regrowth in Khata, one of Nepal's tiger corridors, coincided with a community-managed forestry program to restore forests for tiger dispersal in this region

- identifying trends in tree cover loss over time and effectiveness of various conservation actions (Clements *et al.*, 2014);
- helping decision-makers understand the patterns of loss and potential mitigation options; and
- highlighting best-practice examples of road construction that are followed by conservation action to contribute to the growing trend towards smart green infrastructure (Quintero *et al.*, 2010).

Until recently, the use of satellite data required substantial expertise and funding for the acquisition, processing, verification and interpretation of the raw information (Curran *et al.*, 2004; Gaveau *et al.*, 2009b; LaPorte *et al.*, 2007; see Annex II). Assessing deforestation at the landscape scale provided valuable evidence of the effects of human activity on forests, but the cost and effort needed to obtain the satellite data prevented widespread use of such approaches.

Global Forest Watch (GFW), a new forest change analysis platform, has transformed the process and increased access to the power of satellite imagery. It provides free access to spatially explicit tree cover change data, derived from thousands of

(Joshi *et al*., 2016). Community-based anti-poaching teams now also patrol the forests to prevent wildlife poaching and habitat degradation. Timely knowledge of these positive results would have allowed forest managers to assist the Khata communities and focus official protection work elsewhere.

In contrast, the clearing of forests by people in search of land around Nepal's Basanta corridor has impeded tiger dispersal to the north, resulting in the absence of previously seen tigers from recent surveys. The human settlement process was identified by regional experts, whereas near-real-time forest loss alerts would have notified managers far sooner and enabled them to try to guide the settlement so as to reduce forest loss (Joshi *et al*., 2016).

Updated forest cover information would also have helped small, isolated reserves, such as India's Panna National Park, where tigers were wiped out by poachers and the lack of connectivity to other reserves precluded tiger recolonization (Wikramanayake *et al*., 2011). The park's vegetation and prey base were left intact, but the government had to transfer five tigers from nearby reserves to catalyze population recovery to more than 35 adult tigers.

The tiger habitat assessment was presented at a meeting of environmental ministers from tiger range states in Delhi, India, in April 2016. In the Delhi Pledge for Tiger Conservation, the conference delegates vow "to protect the tiger and its wild habitat to ensure crucial ecological services for prosperity" (PIB, 2016b). Delegates from five countries asked to use the satellite-based monitoring tools presented in the assessment to conduct and update their annual national tiger habitat analyses, and others described how this tool could help them to monitor habitat across the tiger range countries at the same scale (PIB, 2016a). The Global Tiger Initiative, an alliance of governments, international agencies, the private sector and civil society groups whose aim is to prevent the extinction of wild tigers, has also endorsed the approach (World Bank, 2016b).

Doubling the tiger population by 2022 will require moving beyond tracking annual changes in habitat. GFW's new forest loss alert system (at a spatial resolution of 30 m) will soon generate weekly alerts for forests across the tropics (M. Hansen, personal communication, 2017). Once the system is in place, forest managers in range states will be able to receive alerts of forest loss within a certain reserve, corridor or TCL in near-real time and take appropriate action. Tiger range state officials have expressed interest in integrating the weekly forest loss alerts into reserve managers' regular monitoring and reporting activities, as even rapid alerts still require immediate action on the ground to stop habitat degradation and loss.[1] For a relatively poor disperser such as tigers, community forestry programs, government initiatives and other stakeholders should also monitor the extent to which forest connectivity is regained. GFW's weekly updating can help track and even promote these interventions.

Tracking and detecting forest change through tree loss is even more relevant to arboreal animals, such as apes. GFW alerts allow for a weekly assessment of the level of risk posed by the fragmentation of thinly connected forest blocks, which is particularly important for the 20 species of gibbon (GFW, 2014). A continually updated, spatially explicit assessment of forest change will help identify and refine key areas for apes and evaluate the type and degree of threat to enable authorities and resource managers to take appropriate action. By making a population recovery commitment based on Tx2, but for great apes and gibbons, ape range states and conservation groups could jointly create an opportunity to facilitate the flow of attention and resources to key areas within ape habitat.

The maps of tiger habitat and tree cover change can be found online at globalforestwatch.org.

Landsat satellite images at a resolution of 30 m × 30 m, updated annually for the entire world (GFW, 2014; see Chapter 7). As of mid-2017, GFW began offering weekly updates of tree cover change for most ape range states to enable near-real-time habitat monitoring (GFW, 2014; M. Hansen, personal communication, 2017). Ape range stakeholders can use the online GFW tools to view and analyze tree cover loss data for a country or protected area, create custom maps or download data for their target region. GFW thus allows users with basic skills to monitor changes in habitat and generate critical information on forest change that can enhance their conservation efforts or monitor the effects of road building in near-real time.

Case Study Approach

This chapter presents past and expected change in ape forest habitat in three case study sites around roads that were substantially upgraded between 2001 and 2014 (see Annex III) and in one site outside the ape range, in the primate-rich tropical forests of Peru. The first three sites—two in northern Sumatra, Indonesia, and one in western Tanzania—are home to a total of four ape subspecies. The Sumatran sites lie in the Leuser Ecosystem and are home to the siamang (*Symphalangus syndactylus*), Sumatran lar gibbon (*Hylobates lar vestitus*) and Sumatran orangutan (*Pongo abelii*); the site in western Tanzania supports eastern chimpanzees (*Pan troglodytes schweinfurthii*). Peru's rainforests harbor more than 50 primate taxa, and the species numbers at several sites are among the world's highest (IUCN SSC Primate Specialist Group, 2006).

Specifically, the analysis applies the Global Forest Change 2000–14 data set to show the loss of ape forest habitat in areas up to 10 km from individual roads in the years before and after a road's construction or improvement (Hansen *et al.*, 2013). The quantification of tree cover loss over time at a fine scale allows for estimates of the location and scale of the effects of roads on forest habitat, the detection of patterns and the identification of areas where future loss is likely.

Further, the chapter examines aspects of road development associated with negative effects on ape habitat. It also assesses the potential of open-access GFW tools, such as forest loss alerts, and data for: a) fine-scale monitoring of forest surrounding roadways built or expanded between 2001 and 2014; b) quantifying forest loss from infrastructure and associated secondary development; and c) helping reserve managers and others do the same. A description of methods can be found in Annex III.

Recommendations for Road Infrastructure in Ape Habitat

Zoning Roads to Maximize Societal Benefit and Minimize Damage to Ape Habitat

Planning new roads to minimize environmental damage while maximizing societal benefits must include consideration of both their location and design. Of primary importance is the avoidance of new road construction through pristine habitat, where soils are commonly of marginal productivity and which are far away from markets (Laurance *et al.*, 2015b; Quintero *et al.*, 2010; see Table 3.3). Laurance and Balmford (2013) and Laurance *et al.* (2014a) propose global "road zoning" to identify and map the areas where roads would best connect people to markets and resources and where roads should not be built, including areas of primary forest, sensitive habitats, animal dispersal, ► p. 102

CASE STUDY 3.1

Roads Facilitate Industrial-Scale Agriculture Threatening the Leuser Ecosystem in Sumatra, Indonesia

Background

Over the past 50 years, human activity has reduced Sumatra's vast expanse of tropical rainforest to isolated remnants and a few large patches. Oil palm, pulpwood and other large-scale plantations have rapidly replaced the island's natural forest and now occupy 20% of the land area (Abood *et al.*, 2015; De Koninck, Bernard and Girard, 2012). Forest clearing in the north of the island began in earnest in the 1980s and led to the loss of more than half of the formerly intact forests in Aceh province by 2000 (De Koninck *et al.*, 2012).

The Leuser Ecosystem encompasses 25,000 km^2 (2.5 million hectares (ha)), including the Gunung Leuser National Park (GLNP), and is by far the largest and most significant forest remnant in Sumatra. It occupies the last remaining lowland forests and the largely mountainous, biodiverse rainforests of Aceh and North Sumatra province (De Koninck *et al.*, 2012; GFW, n.d.-c). The Leuser Ecosystem comprises 78% of remaining habitat for the Sumatran orangutan and supports more than 90% of the remaining population—an estimated 14,600 individuals (Wich *et al.*, 2008, 2016). It is most probably a critical refuge for the Sumatran lar gibbon and siamang (Campbell *et al.*, 2008; Nijman and Geissmann, 2008). All three taxa are endangered by hunting and habitat loss and require intact forest canopy to survive (Brockelman and Geissmann, 2008; Nijman and Geissmann, 2008).

Established in 1995, the Leuser Ecosystem is a legal entity managed for conservation of the region's biological diversity and designed to contain viable populations of native species (Van Schaik, Monk and Robertson, 2001). Even in this protected area, however, people continue to clear forest and large-scale plantations have come to cover much of the historical ape habitat.

Hunting and the conversion of previously logged forests into monoculture plantations are the two principal threats to the three ape species in the Leuser Ecosystem (Geissmann, 2007; Wich *et al.*, 2011, 2016). Quantifying local hunting pressure is beyond the scope of this analysis. Therefore, road buffer-zone distances were set to reflect the previous finding that wild meat hunting typically extends between 5 km and 10 km from roads, as reported by Laurance *et al*. (2009; see also Annex III).

Incursion of the Ladia Galaska Road Network

Ladia Galaska is a 1,650-km all-weather road expansion effort that is meant to link Aceh's west and east coasts through the province's mountainous interior (De Koninck *et al.*, 2012). Since the mid-1990s, the mega-development project has upgraded and connected previously built roads, including routes that were passable only during the drier seasons. The Ladia Galaska road network cuts across the Leuser Ecosystem's northern section, fragmenting formerly intact forest and threatening forest biodiversity and water supply services for lowland communities.

Ladia Galaska has generated heated debate since it was proposed in the mid-1980s (Eddy, 2015). Aceh's governors have pushed to speed up construction, and many local communities support the project because it would improve their options for transporting palm oil and other commodities (Clements *et al*., 2014).

Critics have argued that Ladia Galaska threatens essential ecosystem services provided by the intact forest, including water supply for several million local residents, erosion and flood control, fire suppression and tourism (van Beukering, Cesar and Janssen, 2003; Wich *et al*., 2011). They also note the reduction and fragmentation of forest that is habitat to numerous iconic and threatened species, including critical orangutan and gibbon populations (Clements *et al*., 2014; IUCN, 2016a). Further, many of the roads are constructed in forested areas with steep slopes that are prone to earthquakes and landslides (Riesco, 2005). Finally, the partially completed project has met with opposition because it will expand access to the area's forests, including the GLNP. By facilitating illegal logging, it will continue to have a negative effect on critically important habitat of all three ape species as well as other unique Sumatran wildlife, including tigers and elephants (Gaveau *et al*., 2009b; Panaligan, 2005; Wich *et al*., 2008).

For this analysis, improvements to roads at two nearby sites served as case studies (see Figure 3.1):

- the Tamiang Hulu–Lokop (TH–L) road in the Leuser Ecosystem's eastern portion; and
- the Blangkejeren–Kutacane (B–K) road that runs through the Ecosystem's center, separating portions of Gunung Leuser National Park.

Roughly 54 km apart, they are two of roughly 16 sections that comprise the Ladia Galaska road improvement scheme (De Koninck *et al.*, 2012).

Tamiang Hulu–Lokop Road Development

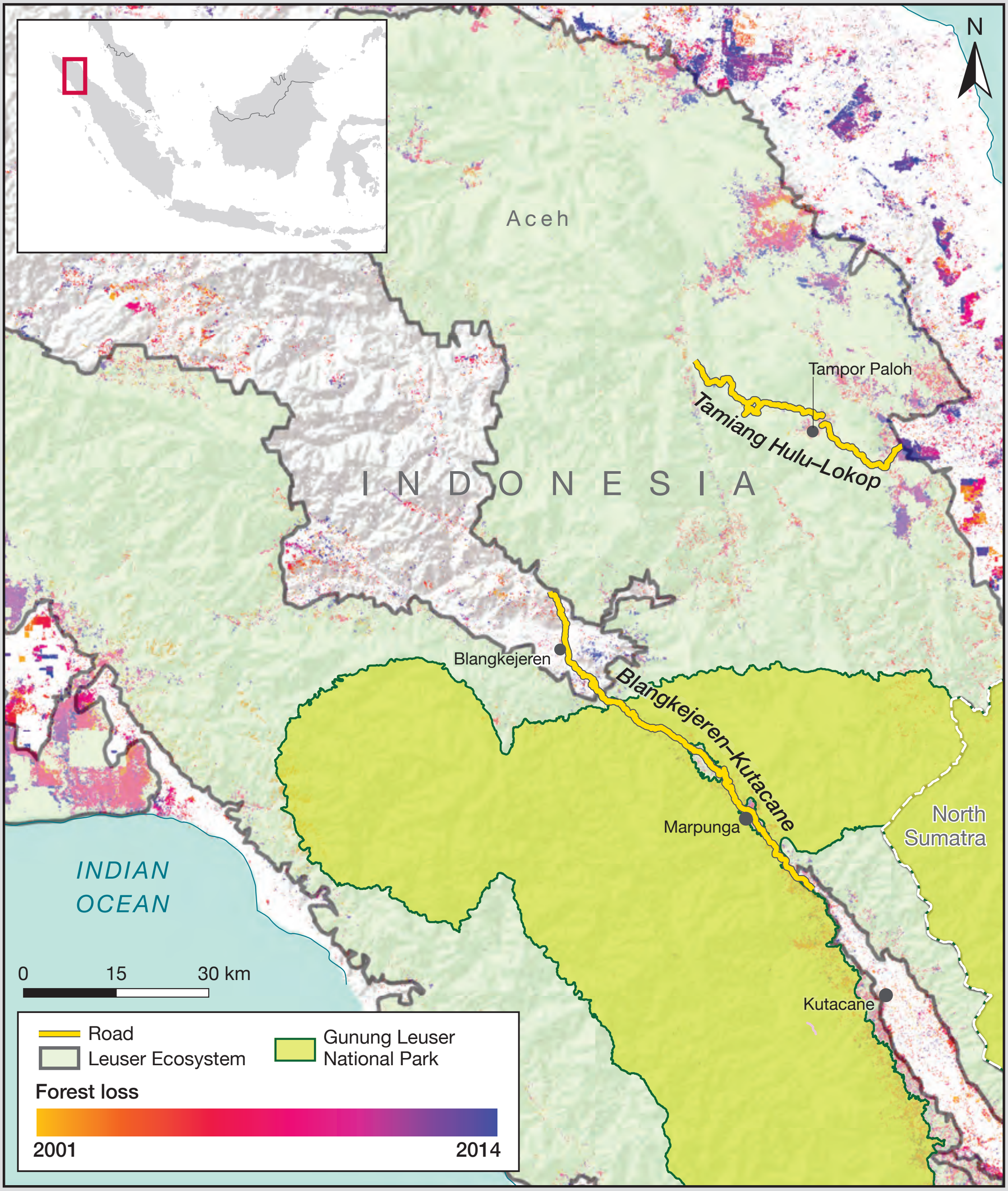
The east–west TH–L route near the village of Tampor Paloh was initially a logging road, visible in the 1980s. It was intensively developed during 2009–10 (see Figure 3.2).

Effects on the Surrounding Area, as Identified by GFW

Roughly 1,072 km^2 (107,200 ha) of forest remained within 10 km of the road in 2000 (see Table 3.1). Of this area, 243 km^2 were within agricultural concessions zoned for conversion to plantations. Prior to 2000, some lower-elevation forest where the road connected to a large oil palm plantation on its eastern edge had already been cleared. Between 2000

FIGURE 3.1

The Tamiang Hulu–Lokop and Blangkejeren–Kutacane Roads in the Leuser Ecosystem, Aceh, Sumatra, Indonesia, 2001–14



Notes: Forest loss is color-coded by year. Yellow–orange colors represent earlier years, and purple–blue colors represent later years.

Data sources: Google Earth Engine Team (n.d.); Hansen *et al*. (2013)[2]

FIGURE 3.2

Eastern Half of the Tamiang Hulu–Lokop Road with Forest Loss, Aceh, Sumatra, Indonesia, 2000–14

Notes: Forest loss is color-coded by year. Yellow–orange colors represent earlier years, and purple–blue colors represent later years. The large clearing at the eastern end of the road is an oil palm plantation established before the year 2000 and is excluded from the analysis.

Data sources: Google Earth Engine Team (n.d.); Hansen *et al*. (2013)[3]

and 2014, additional natural forest was cleared within various concessions.

Most of the forest loss between 2000 and 2014 occurred within concessions that were still in natural forest in 2000 but cleared by 2014. This included 129 km² (12,900 ha) primarily in oil palm concessions within 0–5 km and another 114 km² (11,400 ha) within 5–10 km (see Table 3.1).

Outside of the concessions, the area along the road experienced scattered and limited deforestation before 2007. Between 2000 and 2006, the areas 0–5 km and 5–10 km from the road each lost less than 0.2% of the 2000 forest cover per year (see Figure 3.3). Prior to the road's improvement, most clearing took place immediately along the road or where it intersected rivers or prior clearings (roads, plantations). Much of the initial 2007 spike in deforestation occurred where the road intersected a river, due to an improved crossing and expansion of a local main road along the river's edge.

Improvement of the road in 2009 corresponded to a second surge in deforestation, as tree cover loss spiked again. The area within 5 km of the road lost nearly 0.8% per year for several years, after which the rate of loss declined (although plantation reclearing expanded).

Between 5 km and 10 km from the road, tree cover loss between 2009 and 2014 averaged 1.2% per year, a rate six times higher than the pre-2009 average. Despite improved access to interior forests all along the road, most loss took place in the lowland forests within previously designated concessions at the area's eastern edge or at intersections of the road with other roads or rivers. Deforestation within 10 km along much of the length of the road was limited to scattered small clearings that extended 100–200 m on either side of the roadway.

TABLE 3.1

Tree Cover and Loss in Tamiang Hulu–Lokop Road Buffer Areas, Aceh, Sumatra, Indonesia, as Identified by Global Forest Watch

Buffer	Tree cover, 2000 (km²)	Tree cover loss, 2000–14 (km²)	Forest cover, 2000, excluding mature oil palm (km²)	Loss excluding reclearing (km²)	Total concession area (km²)
0–5 km	485	41	468	23	129
5–10 km	608	57	604	53	114
0–10 km	1,093	97	1,072	76	243

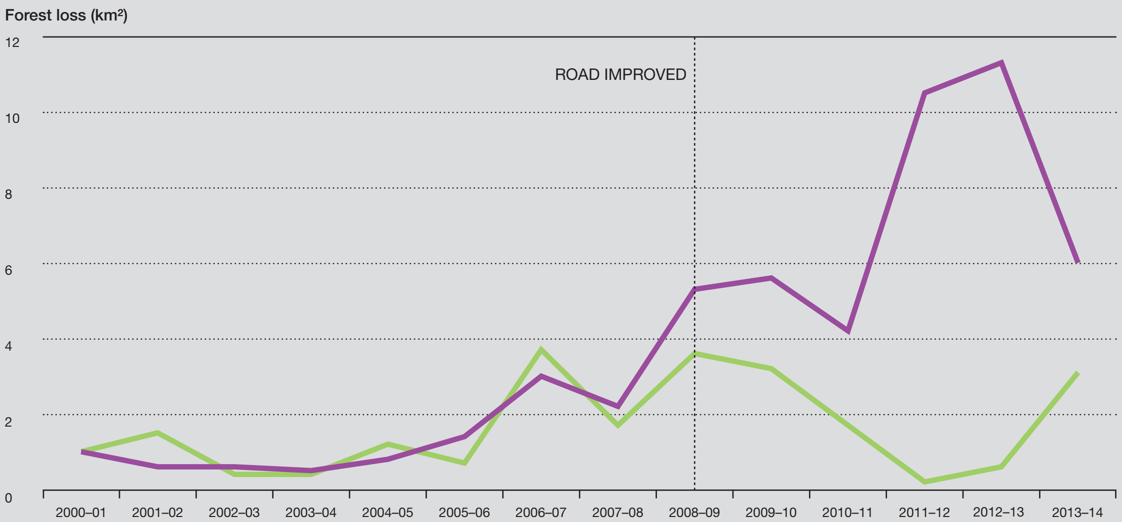
Notes: Values for tree cover in 2000 and tree cover loss in 2000–14 refer to the full extent of tree cover identified by GFW for those years. The values for forest cover in 2000 exclude a 17-km² mature stand of oil palm within 5 km and another 4-km² stand within 5–10 km that GFW mistakenly counted as forest (see Annex III). The reclearing of these areas between 2011 and 2014 was excluded from tree cover loss. Although nearly 25% (243 km² or 24,300 ha) of the total area with tree cover was within large-scale concessions, some of it was still natural forest in 2000.

Data sources: GFW (2014); Hansen *et al.* (2013)

FIGURE 3.3

Forest Loss Within the Buffer Zones of the Tamiang Hulu–Lokop Road, Aceh, Sumatra, Indonesia, 2000–14

Key: 0–5 km 5–10 km



Notes: Road improvements took place in 2009. Loss values exclude the reclearing of a major oil palm plantation in the western edge of the buffer zones between 2010 and 2014 (see Figure 3.2).

Data sources: GFW (2014); Hansen *et al*. (2013)

Addressing Effects of Road Development

The findings suggest that, on its own, the upgrade of the TH–L road caused limited forest loss; however, it negatively affected ape populations because of its role in reducing key lowland forest habitat. Orangutans and lar gibbons favor lowland forest below 1,500 m (Brockelman and Geissmann, 2008; Campbell *et al*., 2008; Van Schaik *et al*., 2001; Wich *et al*., 2016). These species may persist at low densities within Leuser's remaining upland forest (Van Schaik *et al*., 2001; Wich *et al*., 2016). The improved TH–L road may have sped the conversion of lowland forest to oil palm within acknowledged plantation boundaries. Nevertheless, minimal settlement occurred along this route, concentrated along intersections with an existing road and river (see Figure 3.2). The narrow roadway clearing sits in a valley, and its hilly surroundings may have limited the establishment of side roads, which presumably would have led to additional forest clearing and hunting access.

Requiring agricultural concession holders to include in their management plans a series of maps of the forest types, endangered species, protected areas, roads and management activities could help identify where critical habitat may be in jeopardy. Accompanied by enforcement, such plans would encourage thoughtful concession design and enable independent and comprehensive review across a given region (Meijaard and Wich, 2014).

However, the power of Indonesian logging interests and a lack of capacity to control them have minimized restrictions placed on logging and conversion to plantations (De Koninck *et al*., 2012; Robertson, 2002). Most proposed improvements have either disregarded findings of their required environmental impact assessment or have ignored it altogether (Robertson, 2002; Singleton *et al*., 2004).

There is an urgent need to develop a systematic and refined land use monitoring system (De Koninck *et al*., 2012). The transparency afforded through regular monitoring by forest officials at various levels using tools such as GFW could greatly facilitate such efforts.

CASE STUDY 3.2

Roads Facilitate Small-Scale Agriculture and Encroachment into Gunung Leuser National Park, Sumatra, Indonesia

Blangkejeren–Kutacane Road Development

The Blangkejeren–Kutacane route, a section of the road that bisects both the Leuser Ecosystem and the Gunung Leuser National Park, also runs through a valley, but it differs from the TH–L road in that it does not provide access to large-scale plantations. Nevertheless, improved road access into the middle of the Leuser forest has invited serious encroachment and deforestation problems over time.

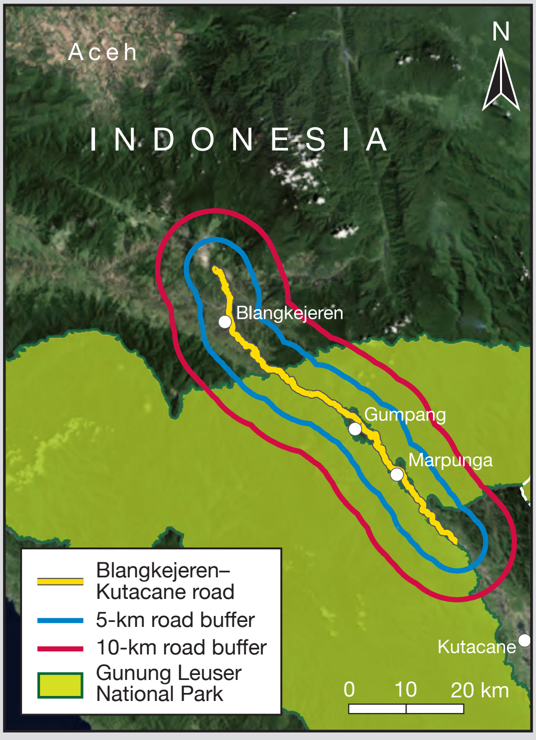
Historically, the B–K road served as a pathway between Blangkejeren and Kutacane. By providing access to the forest, it attracted settlers (Tsunokawa and Hoban, 1997; see Figure 3.4). The road was substantially improved in 2009, and illegal logging and agriculture have since widened the deforested strip along the road, which divides two large sections of the GLNP.

The road has provided transport and market access to two settlement enclaves, Gumpang and Marpunga, which were allowed to remain outside the boundaries of the GLNP (see Figures 3.4 and 3.5). These settlements have since expanded into National Park territory. The road has also provided forest access to loggers, who have illegally cleared sections alongside the adjacent Alas River and into the surrounding protected forest (McCarthy, 2002).

A lack of political will to enforce logging laws and collusion between powerful government officials and timber companies makes illegal logging in Leuser's protected forests especially hard to address (McCarthy, 2000; Wich *et al.*, 2011).

FIGURE 3.4

The Blangkejeren–Kutacane Road, Aceh, Sumatra, Indonesia, Shown With Buffers of 5 km and 10 km, 2016

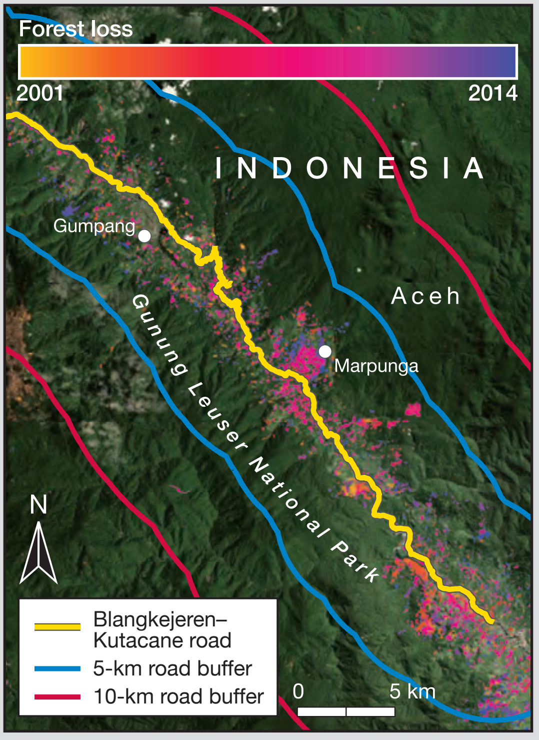


Notes: The road separates the forest blocks of Gunung Leuser National Park (in green). Two settlement enclaves along the road—Gumpang to the north and Marpunga to the south—are visible outside of the park boundary on the map.

Data source: Google Earth (n.d.)[4]

FIGURE 3.5

Section of the Blangkejeren–Kutacane Road with Protected Forest on Both Sides and Forest Loss, Aceh, Sumatra, Indonesia, 2000–14



Notes: Forest loss progresses over time outward from the road, including outward from the concentration of loss in the enclave of Marpunga. The clearing deep inside Gunung Leuser National Park at center left is a landslide.

Data sources: Google Earth (n.d.); Hansen *et al.* (2013)[5]

TABLE 3.2

Tree Cover and Loss in Blangkejeren–Kutacane Road Buffer Areas, Aceh, Sumatra, Indonesia, 2000–14, as Identified by Global Forest Watch

Buffer	Forest, 2000 (km²)	Forest loss, 2000–14 (km²)	Forest loss, 2000–14 (%)	Pre-2009 average annual loss (km²)	Post-2009 average annual loss (km²)
0–5 km	646	53	8.1	2.4	5.5
5–10 km	818	27	3.3	1.3	2.7
0–10 km	1,464	79	5.4	3.7	8.2

Note: No concessions occurred within the buffer areas of this road.

Data sources: GFW (2014); Hansen *et al.* (2013)

Effects on the Surrounding Area, as Identified by GFW

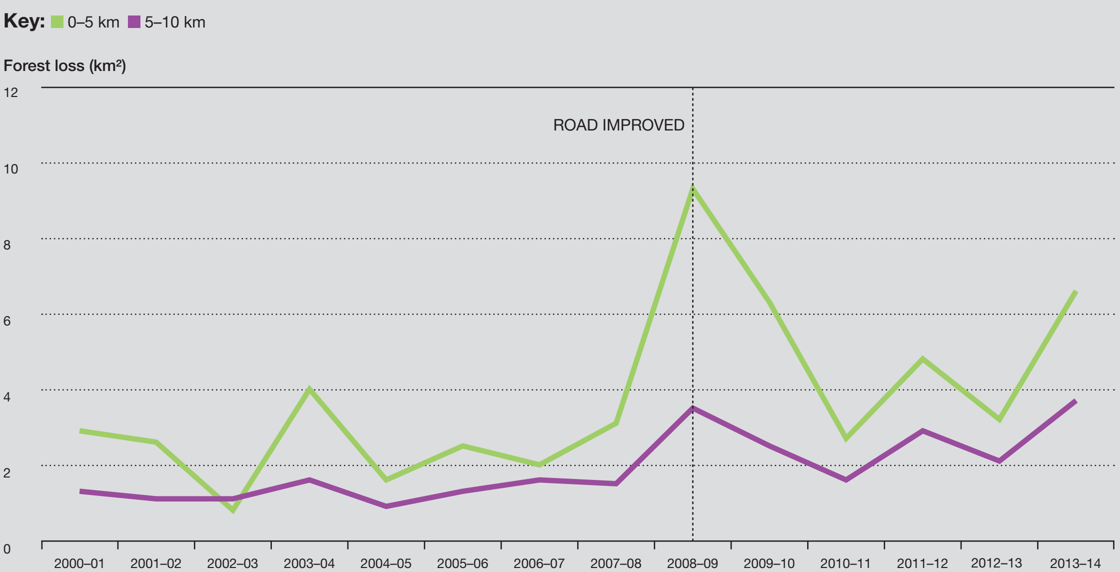
Roughly 1,464 km² (146,400 ha) of forest remained within 10 km of the road in 2000 despite decades of regular use (see Table 3.2). Forest loss between 2000 and 2006 was consistently greater along the B–K road than around the Tamiang Hulu–Lokop road, averaging 1–3 km² per year within 5 km of the road and 1.0–1.5 km² per year within 5–10 km.

The B–K road was upgraded in 2009. Forest loss tripled that year and remained high; the average area of forest lost annually between 2009 and 2014 was more than double that for the period between 2001 and 2008.

Between 2000 and 2008, roughly 3.7 km² (370 ha) of forest was lost each year within the entire 0–10-km buffer area. This rate more than doubled during the years after the road improvement (see Table 3.2 and Figure 3.6). Most of the loss occurred within 3 km of the road. Part of the improved road section runs through Blangkejeren, which was already well settled before 2000 and which lost relatively little additional

FIGURE 3.6

Forest Loss Within the Buffer Zones of the Blangkejeren–Kutacane Road, Aceh, Sumatra, Indonesia, 2000–14

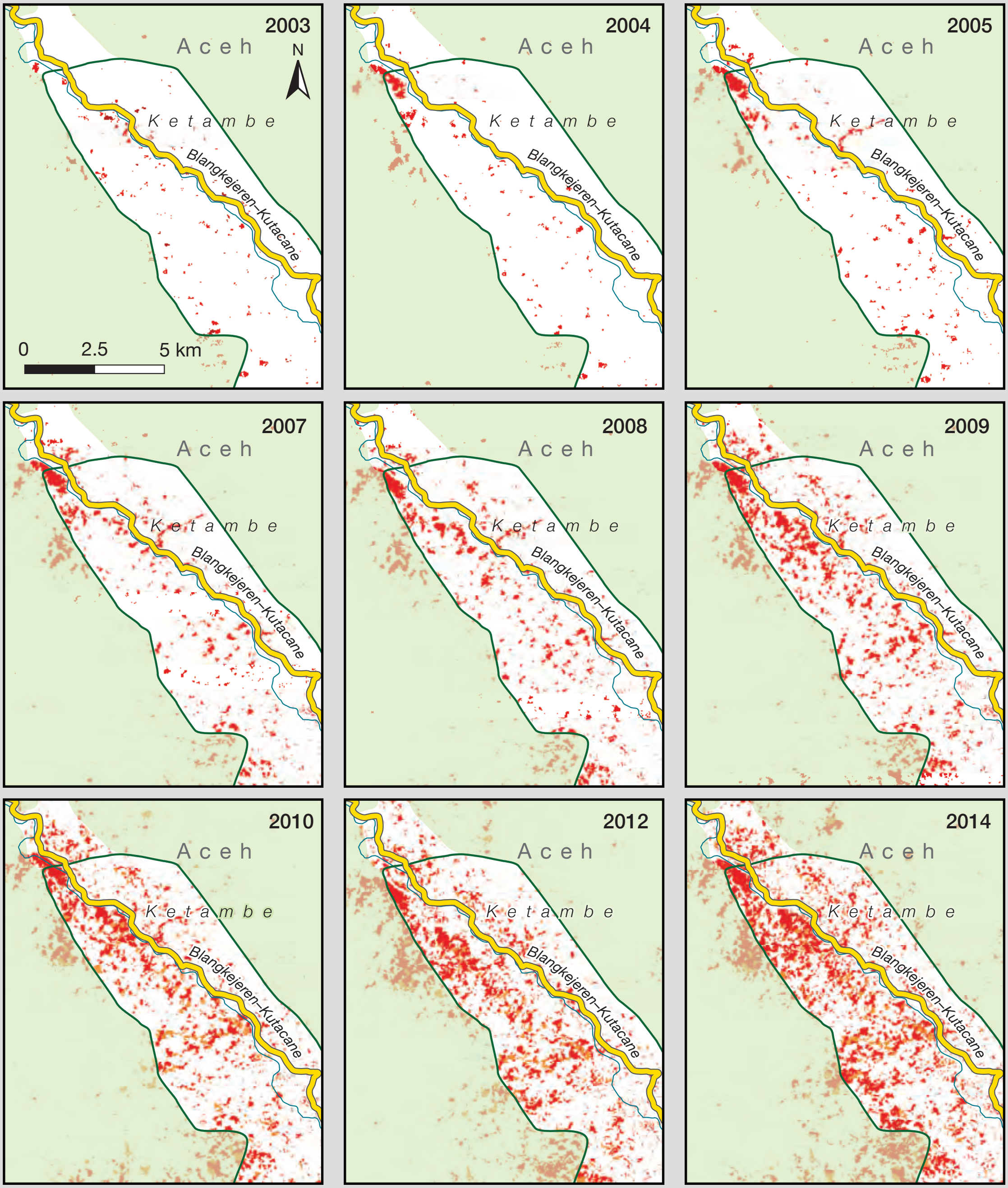


Note: The buffer zones did not contain plantations.

Data sources: GFW (2014); Hansen *et al*. (2013)

FIGURE 3.7

Progression of Forest Loss Along a Section of the Blangkejeren–Kutacane Road, Aceh, Sumatra, Indonesia, 2003–14



Note: Forest, shown in pale green, lies within Gunung Leuser National Park.

Data sources: GFW (2014); Hansen *et al*. (2013). All maps © OpenStreetMap and contributors (www.openstreetmap.org/copyright) forest cover during the study period. Nonetheless, forest loss overall was more extensive on the two ends of the road section, near the established towns.

As with the TH–L road, the 2009 upgrade of the B–K road corresponded to a surge in deforestation (see Figure 3.6). The average rate of loss rose over the following years at both distances from the road, but particularly close to it. Within 5 km of the road, the 0.9% average annual rate of forest loss after the 2009 upgrade was more than double the 0.4% loss rate prior to the upgrade. At a distance of 5 km to 10 km from the road, forest loss between 2009 and 2014 averaged 0.3% per year, also double the pre-2009 average.

One explanation for the negative influence of roads on forest cover is the shifting of loggers' efforts once the road itself is no longer a barrier. As soon as a good road is available, loggers or settlers may be more willing to spend a day clearing forest from a point on the road than if they had already had to travel over 20–50 km of bad road that day. The upgrading of the road facilitated access to interior forests inside the GLNP, despite the hilly terrain that may have limited clearing in steeper areas.

Incursions into the GLNP thus accelerated over time (see Figure 3.7). Progression of forest loss within the park spiked in 2004, building on smaller incursions of the previous two years. Loss spiked again in 2008 and 2009, also after several years of smaller incursions. This pattern of smaller but consistent, incremental clearing along the B–K road stands in contrast to the clearing of larger blocks within the concessions of the TH–L road, where little settlement occurred. The images in Figure 3.7 show the spatiotemporal progression of deforestation inside the GLNP along the B–K road.

Predictive models have shown that forest areas near roads in Aceh are increasingly vulnerable to deforestation. Researchers expect the extent of orangutan habitat to decrease by another 16% between 2006 and 2030, which would cause major declines in the current global population (Clements *et al*., 2014; Gaveau *et al*., 2009b). Forest conversion and fires have followed logging activity along many Indonesian logging roads, heightening the vulnerability of resident ape populations (Clements *et al*., 2014; Laurance *et al*., 2009).

Addressing Effects of Road Development

The Ladia Galaska project is a case of poor land use planning, as exemplified by the B–K road (Wich *et al*., 2008). Whereas the TH–L road facilitated wide-scale conversion of lowland forest to oil palm inside designated plantations, the B–K road bisects the mountainous Gunung Leuser National Park. Aerial photographs taken before and after an earlier (1982) upgrade of the B–K route show that the improved access facilitated uncontrolled illegal settlements inside the park around the Gumpang and Marpunga enclaves (Singleton *et al*., 2004). The improved road enabled the settlers to enter the GLNP illegally, extract resources from the park and poach wildlife. The 2009 improvement further encouraged forest loss around these growing human enclaves, within an otherwise remote national park.

The Leuser Ecosystem is officially protected by presidential decree and provides water for millions of Aceh residents (Eddy, 2015; Singleton *et al*., 2004; van Beukering *et al*., 2003). Nevertheless, some Ladia Galaska roads traverse the region's steep slopes, cutting through protection forests, which have an average slope of 40% or more, as well as conservation forests, including the GLNP and water catchment areas. Scientists at the Center for International Forestry Research have recommended redirecting Aceh's road investment away from remote Leuser forests to existing roads that need improvements along the coast, where more agriculture and settlement occur and forests have been degraded. This shift would benefit more residents and incur lower environmental costs (CIFOR, 2015; Laurance and Balmford, 2013).

Projections based on economic and environmental data suggest that Aceh forests that are near roads have a higher risk of deforestation, leaving viable ape habitat only in the more remote sections of the Leuser Ecosystem (Gaveau *et al.*, 2009b; Van Schaik *et al*., 2001). The indiscriminate spread of clearings along the B–K road and other roads within the Leuser Ecosystem will increasingly fragment the GLNP and two of the three largest remaining orangutan populations.

As the hills within the GLNP are quickly becoming a last refuge for apes on Sumatra, additional conservation action must address not only the access provided by this road and associated settlement enclaves, but also the lack of law enforcement capacity, as both factors enable illegal logging to continue within park boundaries (Eddy, 2015; Robertson, 2002; Wich *et al*., 2011). Along established roads, posts established by local non-governmental organizations (NGOs) and resource managers at road and river checkpoints could help to prevent loggers from entering the GLNP and to confiscate wildlife and logs that are being removed from the park illegally (Singleton *et al*., 2004). Planning new roads so that they avoid or minimize forest clearing will be crucial to apes' persistence in the Leuser Ecosystem (Jaeger, Fahrig and Ewald, 2006; Nijman, 2009).

CASE STUDY 3.3

Stepwise Road Construction through Chimpanzee Habitat in Western Tanzania

Background

The Ilagala–Rukoma–Kashagulu (I–R–K) road in the west of Tanzania has facilitated settlement of forests and woodlands east of Lake Tanganyika (see Figure 3.8). The region contains large tracts of intact woodland characterized by *Brachystegia* species (spp.) and *Julbernardia* spp. that provide high-quality habitat for a diversity of species, including the eastern chimpanzee (Piel *et al*., 2015). Forested lands to the south of the Malagarasi River are under increasing threat from a human population growing at an annual rate of 2–5%, one of the highest rates in Tanzania.

The study area includes 20 villages, most of which lie along the lakeshore, and areas in six land tenure categories—village forest reserves, other demarcated village lands, Kungwe Bay Forest Reserve, local authority forest reserves, Mahale Mountains National Park (MMNP) and general land not reserved for a specific use or a particular village. Fishing and subsistence farming are the region's main economic activities; hunting is not a major economic venture in this region.

The road runs along the shores of Lake Tanganyika, from the Malagarasi River south to the southern border of the MMNP. Fewer than one-third of Tanzania's 2,500 chimpanzees live inside Gombe and Mahale Mountains National Parks, where they are well protected (Moyer *et al*., 2006; Piel *et al*., 2015; Plumptre *et al.*, 2010). Most chimpanzees in the region live at lower population densities outside protected areas. The most recent draft of the Tanzania National Chimpanzee Management Plan considers infrastructure, settlements and smallholder agriculture "very high" threats to chimpanzees and habitats at the national scale (TAWIRI, in preparation). A previous analysis, carried out in 2011 using the same methodology, ranked settlements and infrastructure as "high" (Lasch *et al*., 2011); the reassessment suggests that the threat from infrastructure development increased from 2010 to 2016.

Incursion of the Ilagala–Rukoma–Kashagulu Road

The I–R–K road is the primary infrastructure development in the region. It is being built in sections. Section A of the road—between the Malagarasi and Lugufu rivers—connected villages along the lakeshore long before 2000 (see Figure 3.8). It was expanded during the main road construction phase in 2006–07, when a bridge was built across the Lugufu. The absence of a bridge prior to 2007 had limited travel between areas north and south of the river. Similarly, no road existed south of the Lugufu River before 2007, when extension of the road began. Subsequent sections were built over the next seven years, as funding became available. No road planning or impact assessment of its design or implementation was conducted for Sections A–E (K. Doody, personal communication, 2017).

Construction plans foresee an extension of the road southward, as a way of connecting Rukoma village, north of the MMNP, with remote villages south of the park. Narrow dirt roads of cleared vegetation already run from Rukoma for 20 km, connecting scattered settlements east and south of the MMNP (Sections E and G). As of 2017, a 13-km segment of Section F of the road, along the eastern boundary of the MMNP, was still at the proposal stage (see Figure 3.8).

Effects on the Surrounding Area, as Identified by GFW

Before 2006, areas across the region experienced moderate forest loss, even before road construction, as people were already living in the area and converting forests to farmland (see Figure 3.9). The building and upgrading of the I–R–K road, beginning in 2006–07, correlated with dramatic increases in forest loss, particularly within the 0–5-km buffer in the Lugufu–Ntakata area (5.5 km² or 554 ha), where the new road bisected large patches of pristine forest and miombo woodland. In the Masito area, a smaller 2007 spike in tree cover loss (1.2 km² or 121 ha) within the 0–5-km buffer reflected the area's already diminished forest cover, as deforestation along the existing dirt road there had begun prior to 2000. In contrast, no spike in forest loss occurred in 2007 in the Mahale East area, as the corresponding road section was not yet built. The increase in forest loss in Mahale East after 2011 is probably due to a gradual influx of settlers from shoreline villages north and south of the MMNP via dirt tracks.

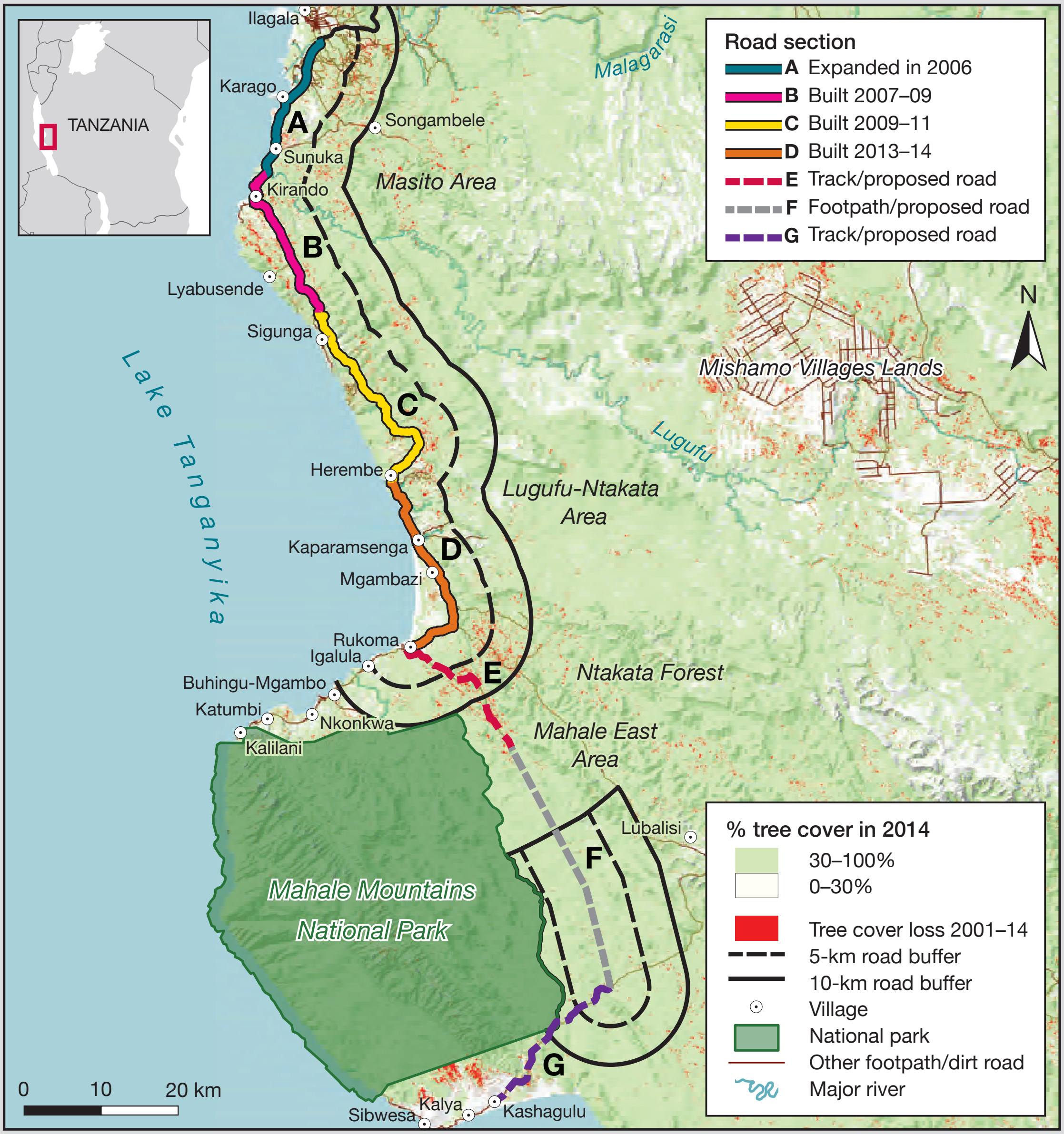
Both high-resolution satellite images and community forest monitoring data indicate that the most important drivers of deforestation within areas up to 10 km from the road are the building of side roads and houses, farming, livestock grazing and charcoal production. The improved road in Section A and new road in Sections B–D facilitated residents' access to new agricultural and charcoal markets in Kigoma, north of the study area, and made it easier for people from villages north of the Malagarasi River to migrate south and settle in previously remote forest and woodland.

The road's construction in 2006–07 corresponded to a wave of forest loss reaching beyond the 10-km buffer in both the Masito and Lugufu–Ntakata areas (see Figure 3.10). In Lugufu–Ntakata, the largest forest loss in all years occurred within the 0–5-km buffer area, and forest loss decreased with distance from the road. In Masito, greater forest loss occurred in areas between 5 km and 10 km from the road. The road that existed in Masito before 2007 connected to an extensive network of footpaths. It is therefore likely that substantial forest within 5 km of the main road had already been lost in Masito before 2007.

An alarming trend in both Masito and Lugufu–Ntakata is the increase in forest loss 25 km to 30 km away from the I–R–K road—at levels significantly higher than before 2007. Most of these areas lack roads, enabling chimpanzees to range and disperse across the landscape. The Ntakata Forest east of Rukoma, the current terminus of the paved road, is critical habitat for chimpanzees, as it allows dispersal of individuals from and to the MMNP chimpanzee population (see Annex V).

FIGURE 3.8

Distribution of Forest and Woodland Vegetation with 5-km and 10-km Buffers Along the Ilagala–Rukoma–Kashagulu Road, Tanzania, 2000



Notes: Letters refer to road sections built during different time periods. A dirt road in Masito (Section A) was improved and expanded in 2006. Between 2007 and 2013, Sections B–D in Lugufu–Ntakata were built, and a narrow dirt road cleared in Sections E and G. Section F surrounds a proposed future stretch of the road. The analysis excluded areas inside the MMNP because habitats within the park were relatively well protected during the study period. Forest and woodland vegetation were defined as areas with a tree cover density of more than 30% (see Annex III). ArcGIS Desktop (Esri, 2016) was used to digitize road construction based on DigitalGlobe satellite images from 2003–16, using the ImageConnect 5.1 plug-in; Google Earth was used to digitize road construction based on Landsat satellite images from 2000–16.

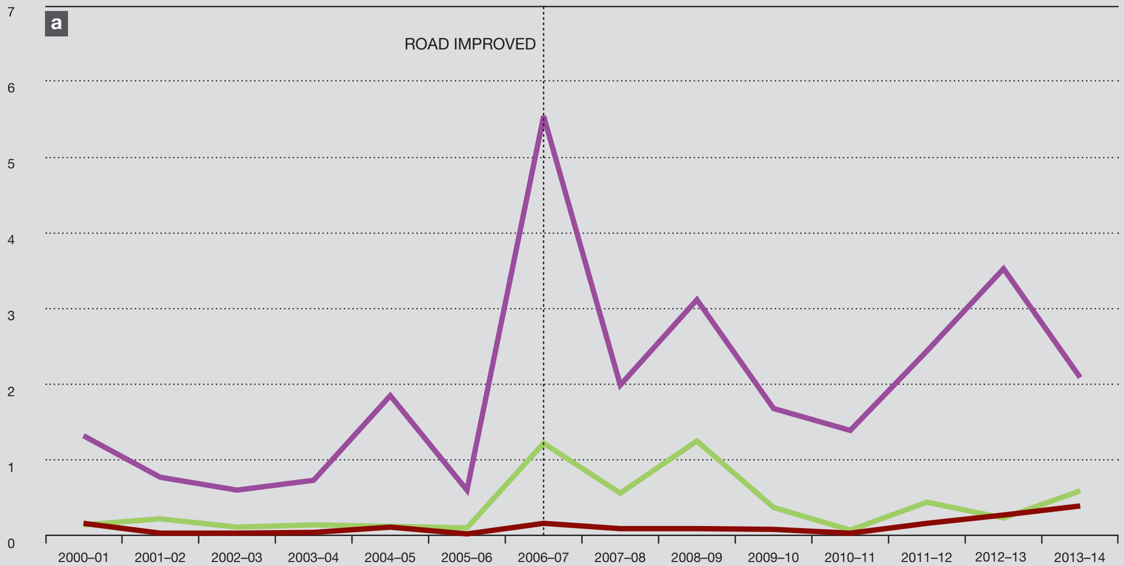
Data sources: Hansen *et al*. (2013); OpenStreetMap (n.d.)

FIGURE 3.9

Forest Loss in the Ilagala–Rukoma–Kashagulu Road's (a) 0–5-km and (b) 5–10-km Buffer Zones, Tanzania, 2000–14

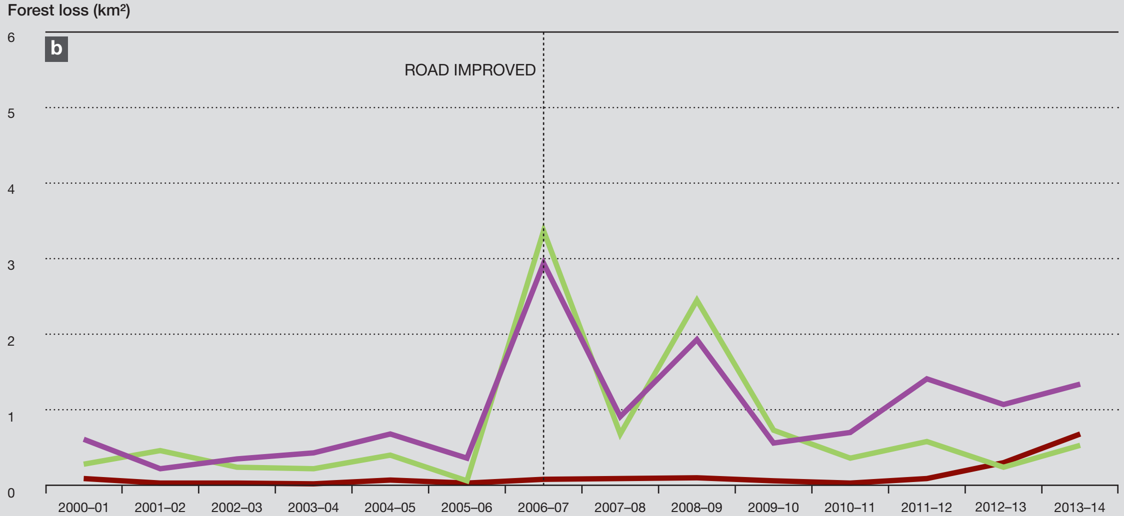
Key: Masito 0–5 km Lugufu–Ntakata 0–5 km Mahale East 0–5 km

Forest loss (km^2)



Key: Masito 5–10 km Lugufu–Ntakata 5–10 km Mahale East 5–10 km

Forest loss (km^2)



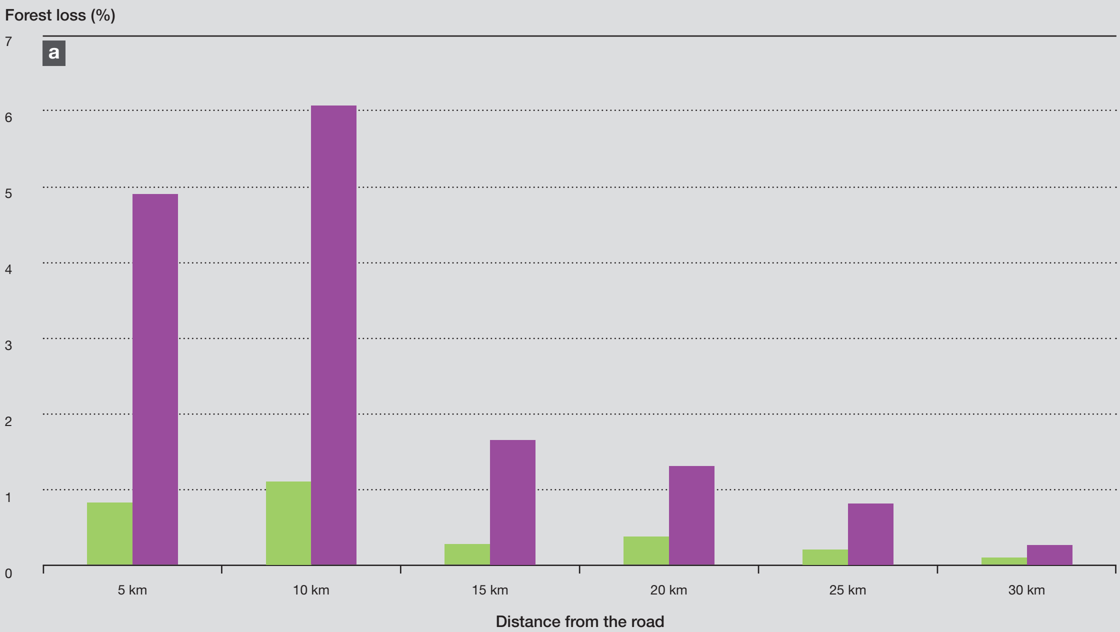
Notes: Lines correspond to the northern Masito, central Lugufu–Ntakata and southern Mahale East areas (Sections A, B–E and F, respectively, in Figure 3.8). The road development expanded a road in Masito and involved the construction of a new road to the Lugufu–Ntakata area. Tree cover loss spiked in 2007 in both Masito and Lugufu–Ntakata; deforestation continued at an elevated rate in Lugufu–Ntakata. The road has not yet reached the Mahale East area, to the south of the existing road.

Data sources: GFW (2014); Hansen *et al*. (2013)

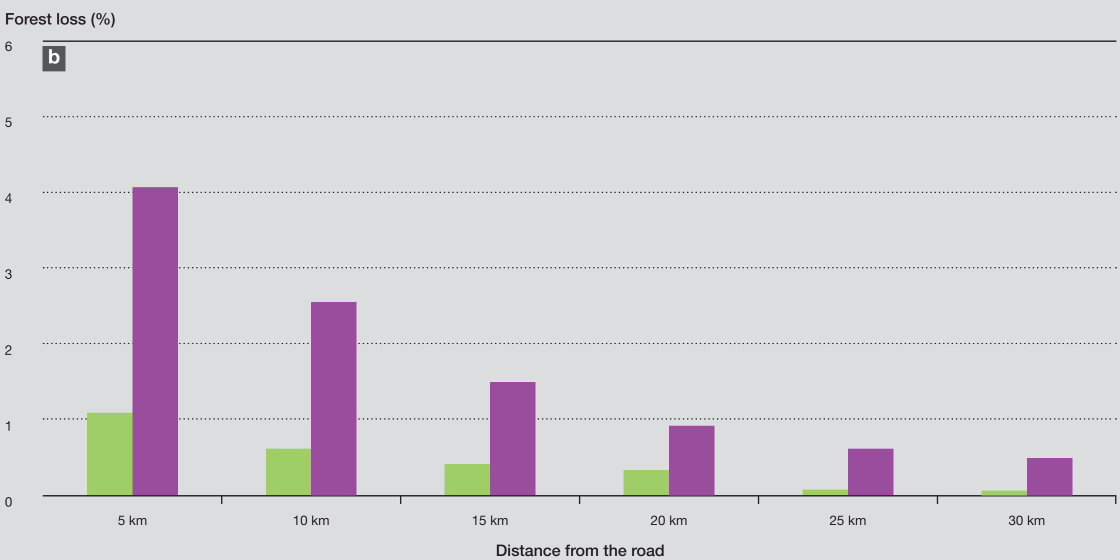
FIGURE 3.10

Forest Loss Before and After Road Construction Within 5–30 km of the I–R–K Road in the (a) Masito and (b) Lugufu–Ntakata Areas, Tanzania, 2001–06 and 2007–14

Key: Pre-road (2001–06) Post-road (2007–14)



Key: Pre-road (2001–06) Post-road (2007–14)



Note: In Masito, the original road was expanded in 2006; road sections in the Lugufu–Ntakata region were built between 2007 and 2013.

Data sources: GFW (2014); Hansen *et al*. (2013)

Tanzania's National Roads Agency (TANROADS) has permission and funding to clear an 18-km stretch of forest and woodland to build Section F, the next planned segment of the road (see Figure 3.8). The potential impact of building this section and upgrading existing footpaths and dirt roads along Section E is a cause of concern for chimpanzee conservationists. The increased access provided by these tracks has already hastened forest loss north and northeast of the MMNP. Unless it is properly planned and managed to restrict illegal settlements, the construction of the new road east of the park is expected to increase rural population density, intensify deforestation, and contribute to isolation of Tanzania's largest remaining and well-protected chimpanzee population in the MMNP—about 550–600 individuals. It also threatens the large numbers of chimpanzees living outside the park, partly because they depend on the zone of connectivity between MMNP and the Ntakata Forest.

Photo: © Jabruson 2018 (www.jabruson.photoshelter.com)

The road itself will not stop chimpanzee movements; however, it will attract settlers who will clear adjacent forest to farm, graze livestock or burn charcoal in this otherwise remote region. Most of the area alongside the new road is general or village land and lacks any form of protection. Loss of intact, roadless areas for the most densely populated chimpanzee habitats in the region will have disastrous consequences for the overall health and viability of chimpanzees in Tanzania.

Addressing Effects of Road Development

As part of a conservation action planning (CAP) process, some communities along the road have developed village land use plans and established village forest reserves based on recommendations for mitigating habitat loss (Lasch *et al*., 2011). If they were to be granted protected status, these reserves could help maintain forest cover along the road and serve as buffers between the road and the core chimpanzee habitats.

Plans resulting from subsequent CAP processes have called for the identification of areas where roads are likely to expand into critical chimpanzee habitats and the application of a hierarchy of mitigation strategies for greening infrastructure (Plumptre *et al*., 2010; Quintero *et al.*, 2010; TAWIRI, in preparation; see Table 3.3 and Annex V). The plan for the Mahale region advises against building the remaining sections of the road, suggesting that, at a minimum, the routes be moved farther away from the MMNP. If Section F of the road must be built, the plan urges development and implementation of a detailed land use plan to protect the forest on either side of the road, so that chimpanzees can cross the road safely and use the surrounding habitat.

Conservation groups have met with TANROADS to design the new section and to address the potential loss of chimpanzee habitat as people use the new road to move into the area (K. Doody, personal communication, 2017). In principle, TANROADS agreed to conduct an environmental impact assessment. Continued dialog between the TANROADS road developers, Uvinza district government, communities and conservation practitioners will be critical to the proper design of future road improvements and to the implementation of conservation strategies to avoid unplanned settlement and conversion of forests to other land uses.

One such strategy is to establish a new, locally administered protected area that serves as a buffer against future loss of forest and woodland along the road. Tanzania's ongoing conservation action planning processes, such as the chimpanzee management planning process, provide an opportunity to integrate road development, land use and other chimpanzee conservation efforts at the national level to maximize societal benefits from future roads while minimizing the effects on chimpanzees and biodiversity in general.

CASE STUDY 3.4

Integrating Forest Loss Alerts with In-Depth Analysis to Tackle Deforestation in Near-Real Time

An innovative forest mapping effort in primate-rich Amazonian forests may provide a useful model for monitoring ape habitat at a fine scale. The Monitoring of the Andean Amazon Project (MAAP) integrates and applies a suite of remote sensing tools to detect and monitor the status of deforestation events (MAAP, 2016, n.d.). The project team combines Landsat satellite images (which are of medium resolution) with high-resolution images from DigitalGlobe and Planet, radar-based imagery and Global Land Analysis & Discovery (GLAD) forest loss alerts to identify patterns and drivers of deforestation in near-real time (GLAD, n.d.; see Annex IV).

The MAAP team's first step in identifying deforestation hotspots is receiving a GLAD alert in the area. On a weekly basis, the GLAD system accesses and analyzes Landsat imagery across the tropics. GLAD alerts are triggered when a threshold portion of a 30 m × 30 m pixel in a user's area of interest changes from forest to non-forest cover (Hansen *et al.*, 2016). The team allows the alerts of tree cover loss to guide their investigations into deforestation events. Each of the thousands of GLAD alerts is presented as a pink spot on a map (see Figures 3.11 and 3.12). MAAP's area of interest is all of Peru, but the selected area could instead comprise a specific protected area, a road corridor or a multi-country region.

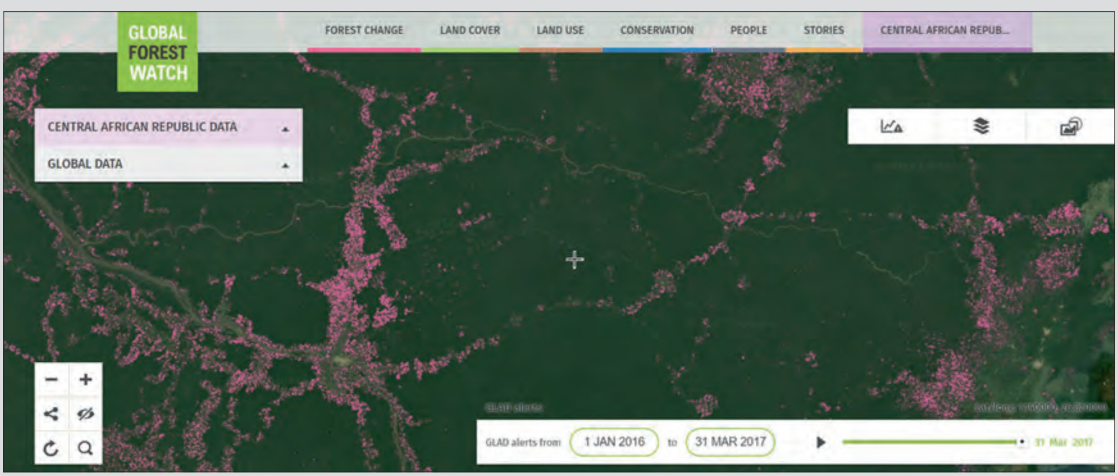
The MAAP team reviews the high-resolution imagery of a target spot from different time periods to confirm that the alert represents deforestation. The team can then bring the alert data into a geographic information system (GIS) to produce a detailed map or to investigate drivers of the forest loss (see Figure 3.12b–c).

At this writing, the MAAP team was improving its analysis of the distribution and intensity of alerts to identify overarching patterns and drivers of deforestation (M. Finer, personal communication, 2016). MAAP analyzed the average size of deforestation events in the Peruvian Amazon to help NGOs and national authorities understand deforestation patterns and prioritize response actions. The analysis found that large-scale deforestation (more than 50 ha)—mainly from cacao and oil palm plantations—accounted for just 8% of deforestation events, while small-scale deforestation (fewer than 5 ha) from clearings along roads made up more than 70% of deforestation events (MAAP, 2016). Since larger-scale clearing can expand rapidly, these monitoring activities need to remain a priority.

GLAD already operates in much of the Congo Basin, Indonesia and Malaysia, and it should be available to help managers easily and consistently monitor all tropical forests by late 2017 (GFW, 2014). By helping to detect habitat loss at the onset of road building, alerts will facilitate more timely, and therefore more effective and efficient, interventions (Hansen *et al*., 2016). Since forest loss alerts provide rapid updates, they can help guide associated development and enforcement, as they have in Peru, to ensure that no additional illegal development happens along roads where restrictions or planning regulations have been established.

FIGURE 3.11

Sample Set of GLAD Forest Loss Alerts Near Kisangani, Democratic Republic of Congo, January–March 2017

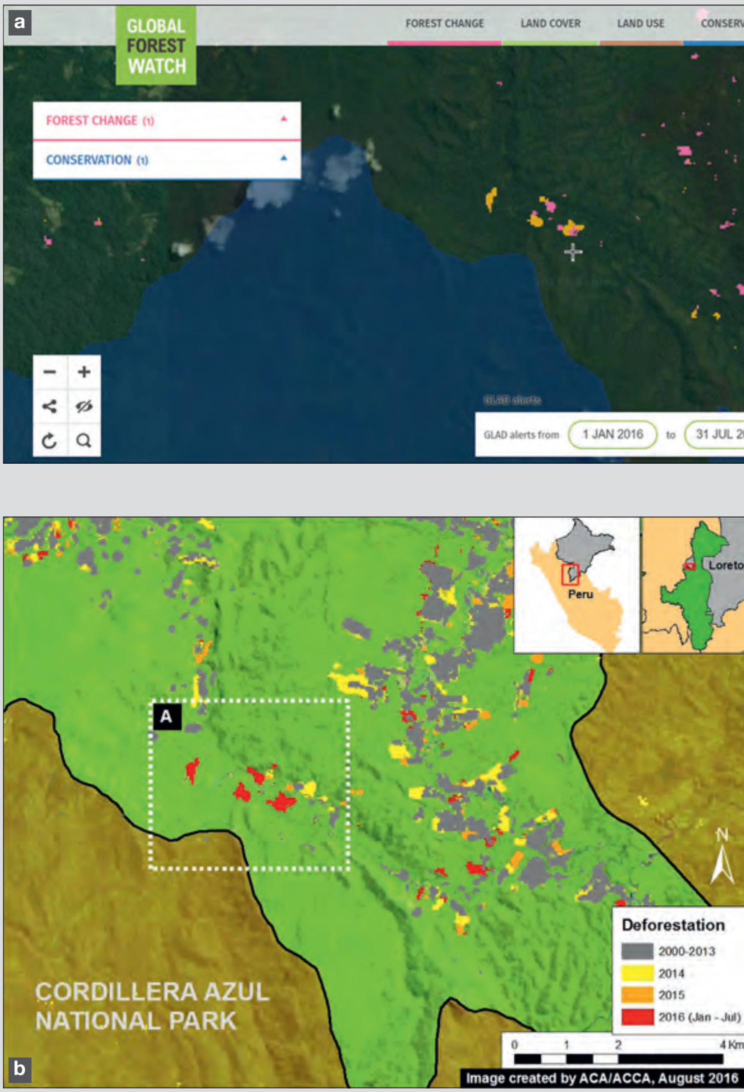


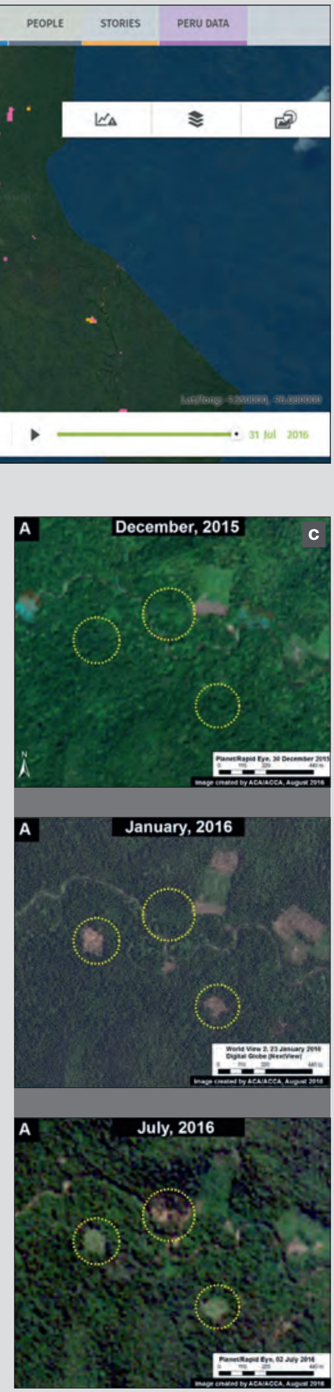
Notes: The image shows deforestation along roads and rivers, emphasizing the relationship between the access provided by these transport corridors and forest loss.

Data sources: GFW (2014); Hansen *et al*. (2013)

FIGURE 3.12

Sample Set of Images Showing the Process of Examining and Integrating GLAD Forest Loss Alerts into Forest Trend Mapping Near Cordillera Azul National Park, Peru, January–July 2016





Notes: The images show illegal forest clearings in a protection forest. The initial (a) GFW alerts can be downloaded and combined with other data in a (b) geographic information system (GIS) and examined in greater detail with (c) high-resolution satellite imagery to help determine drivers of forest loss.

Data sources: (a) GFW (2014); Hansen *et al*. (2013); MAAP (2016); (b) and (c) DigitalGlobe (n.d.); MAAP (2016); Planet (n.d.)

Photo: Siting a new road in areas with substantial economic activity, such as northern Aceh, rather than through a large tract of intact forest, could improve farmers' market access and avoid a possible environmental disaster.

migratory routes and unique natural communities. However, many decision-makers fail to consider these factors during road planning processes. The consequences can be devastating to natural environments while wasting time and money connecting areas in ways that help relatively few people (Laurance *et al.*, 2015b; see Chapter 1, p. 28).

Current road planning and mapping efforts inadequately assess environmental and socioeconomic impacts, and especially the indirect effects, such as unplanned colonization, hunting and secondary road building (Clements *et al.*, 2014; Laurance *et al.*, 2014a). Roads that stimulate uncontrolled immigration lead to greater satellite clearing and other forest damage by settlers (Angelsen and Kaimowitz, 1999; Liu, Iverson and Brown, 1993). Chimpanzees and orangutans appear to tolerate some road presence. However, the subsequent conversion of newly accessible forest to settlements, farming, charcoal and other uses encourages further forest clearing and hunting, a major threat to apes and other large-bodied animals (Laurance *et al.*, 2006, 2009).

If building new transportation infrastructure cannot be avoided, best practices can help to minimize negative consequences for the surrounding ecosystem (see Table 3.3). Monitoring logging roads and closing them after extraction ends can restrict access to illegal loggers and animal poachers (Laurance *et al.*, 2009). Following recommendations of environmental impact assessments that consider both roads and associated clearing and hunting and conducting enhanced patrolling and monitoring of forest on both sides of a road can further help to minimize the negative effects of infrastructure on forest ecosystems (Clements *et al.*, 2014; Quintero *et al.*, 2010).

Rerouting a proposed road may be the cheapest and most effective means of avoiding areas of critical wildlife habitat, but in poor countries covering this additional cost will probably require creative fundraising (Quintero *et al.*, 2010). Fees from ecotourism income and visitors, international payments for ecosystem services, public–private partnerships and sales of sustainably harvested timber within

TABLE 3.3

The Mitigation Hierarchy

Mitigation step	Description
Avoidance	Measures taken to avoid negative effects from the outset. These include careful spatial or temporal placement of elements of infrastructure in ways that completely avoid harming certain components of biodiversity.
Minimization	Measures taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided, as far as is practically feasible.
Rehabilitation/ restoration	Measures taken to rehabilitate degraded ecosystems or restore cleared ecosystems following exposure to effects that could not be completely avoided and/or reduced.
Offset	Measures taken to achieve no net loss of biodiversity, by compensating for any significant adverse effects on biodiversity that could not be avoided or reduced, and/or by compensating for lost biodiversity that could not be rehabilitated or restored. Offsets can involve restoring degraded habitat, arresting degradation, averting risk or preventing at-risk areas from experiencing biodiversity loss.

Note: For more information, see Chapter 4, p. 119.

Source: Quintero *et al*. (2010)

production forests could help offset costs, pay for the rerouting of a road or allow for the mitigation of its environmental impacts (Dierkers and Mattingly, 2009; Laurance *et al.*, 2014a). Park entry fees or impact fees for roads that transit protected areas can and should be used to minimize associated clearing in adjacent forest. Engaging lenders early in the process can help to guide funding to less damaging projects (Laurance *et al.*, 2015a). Concentrating roads in already developed areas should make construction and maintenance costs, as well as use fee collection systems, more cost-effective. Such efficient use of funds could encourage international banks to support a project.

Applying Road Planning to the Local Context

Refining the global map of Laurance *et al.* (2014a) using local-scale data on distributions of natural resources and human communities for specific proposed roads could guide decision-makers in determining whether and where to site new roads. Siting a new road in areas with substantial economic activity, such as northern Aceh, rather than through a large tract of intact, unprotected forest, such as Gunung Leuser National Park, could improve farmers' market access and avoid a possible environmental disaster (Rhodes *et al.*, 2014; Wich *et al.*, 2011). In the case in western Tanzania, this protocol would call for avoiding a new road through the single remaining habitat corridor for chimpanzees and other woodland species in and out of Mahale Mountains National Park. In that context, integrating road planning with village land use planning and data collection, as recommended by Tanzania's CAP process, could help reduce local habitat loss (Clements *et al.*, 2014; see Annex V).

> "Development banks and other major funding bodies have a key role in supporting efforts to harness the capacity of roads to improve local economies without damaging natural resources."

Laurance and Balmford (2013) suggest collaborative, multidisciplinary teams that combine satellite data on forest cover with information on transportation infrastructure, agricultural production, biodiversity distribution and other relevant factors to produce maps that can help government and other stakeholders plan roads in ways that achieve environmental and societal goals. Development banks and other major funding bodies have a key role in supporting efforts to harness the capacity of roads to improve local economies without damaging natural resources. Open-access monitoring tools would allow such integrated, cross-agency teams to analyze the effects of infrastructure-related development to improve monitoring and planning for future developments.

The dynamics of road infrastructure and human activity are complex and often case-specific. Roads not only respond to, but also stimulate, increased human population density. Some roads, such as those in western Tanzania, are built specifically to support existing settlements. Elsewhere, speculators are known to purchase and clear forested land to demonstrate ownership in anticipation of the progression of a new road into hitherto intact forest (Angelsen and Kaimowitz, 1999). Moreover, deforestation where roads are built to transport minerals, logs or palm oil from vast cleared areas that have few people may not depend directly on population density (Curran *et al.*, 2004; Kummer and Turner, 1994). Independent information sources are therefore essential to understanding the deforestation that accompanies various categories of roads.

The Potential of Remote Sensing Tools to Detect and Monitor Changes in Ape Habitat

Remote sensing imagery can serve as an independent source of information. At some point over the course of new infrastructure development, such imagery will capture the tree cover loss that results from construction and subsequent human activity. Through the above-mentioned weekly forest loss alerts, the detection of tree cover change will be sped up dramatically (see Annex IV). These data can be strengthened by undertaking ape habitat mapping and analysis using landscape metrics to assess habitat connectivity, fragmentation and patch size, shape and richness in relation to ape distribution and abundance (M. Coroi, personal communication, 2017).

Resource managers in ape range countries can verify the effects of infrastructure on forest cover by contrasting the status of surrounding forest before and after infrastructure projects in analyses similar to the ones presented in this chapter's case studies. Forest loss and land cover data can help predict where ape habitat and populations may already be degraded. Managers can complement data on a proposed road with lessons learned from previous case studies to inform the process of determining the new road's location and design. Proposed roads and other developments indicate where remaining ape populations will be most affected in the future (Laurance *et al.*, 2006). Detecting and monitoring loss of forest habitat in ape range countries through rapid analysis will also help managers to reduce the effects of infrastructure presence through targeted local action.

The drivers and patterns of deforestation in these cases vary by location, yet the spike from road-associated development is seen consistently in all cases and at various distances from the respective roads. GFW forest change analysis tools can help researchers, managers and policymakers to quantify changes in forest cover over time, from both road construction and the subsequent development associated with it. The accumulation of spatially explicit forest change data allows users to communicate these changes to policymakers and to maintain decision-making transparency.

The increasing fragmentation and conversion of ape habitat documented elsewhere in this volume underscore the importance of road construction as a proximate driver of that loss. Dealing with the underlying drivers of habitat loss is beyond the scope of this analysis, although they must also be addressed. In view of the ongoing expansion of road networks, the simplest solution is to focus on improving roads close to population centers; while at the same time avoiding the construction of new roads in intact forests and stopping the upkeep of roads that once were used for extraction purposes, so that forest access may be cut off (Clements *et al.*, 2014; Laurance and Balmford, 2013).

Numerous studies cited here and elsewhere suggest that roads and wildlife do not coexist well in any country unless stakeholders adopt principles of smart green infrastructure. A shift to a model that embraces these principles must become a prerequisite for development in all wildlife habitats, including in regions that harbor remnant wild ape populations.

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Endnotes

1 Author interviews with delegates at the Third Asian Ministerial Conference on Tiger Conservation, New Delhi, April 2016.

2 Map sources: Aerogrid, AEX, CNES/Airbus DS, DigitalGlobe, Earthstar Geographics, Esri, GeoEye, Getmapping, IGN, IGP, NOAA, swisstopo, USDA, USGS and the GIS User Community

3 See endnote 2.

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