GE Trees, Cellulosic Ethanol, and the Destruction of Forest Biological Diversity

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As food riots spread across the globe in response to skyrocketing prices and shortages resulting from mounting competition between food and crop-based agrofuels, the cellulosic ethanol industry is heavily promoting fuel produced from trees as the solution to this conflict. However, ethanol from trees is not a solution. Rather, it will have dangerous ecological impacts as well as harm indigenous and rural communities. In many countries of the world, industrial timber plantations already compete with agricultural land. And as oil prices continue to hit record highs, the lure of enormous profits is greatly increasing incentives for ethanol-producing tree plantations, which can only exacerbate the competition for land between timber plantations and agriculture. Under this scenario, we can expect to see accelerated deforestation and illegal logging in forests all over the world, with serious consequences for forest biological diversity, forest-dependent communities, and the climate.

In the Lumaco District of Chile, for example, the expansion of pine and eucalyptus plantations is taking over agricultural land used by indigenous Mapuche communities and dramatically escalating the rate of poverty. Between 1988 and 2002, plantations in this region increased from 14 percent of the land to over 52 percent. In the Lumaco District 60 percent of the people now live in poverty, one-third in extreme poverty. The government of Chile exacerbates the problem by providing financial incentives to encourage people to grow trees instead of food. Lucio Cuenca**,** the National Coordinator for the Observatorio Latinamericano de Conflictos Ambientales in Santiago, Chile explains:

> The response by the State has been to provide favorable legal and social conditions to enable the forestry companies to fulfill their production goals and continue their expansion. On the one hand, repression and criminalization [of Mapuche opposition]. On the other … rerouting subsidies formerly aimed at the large forestry companies towards the small farmers and indigenous land owners oblige them to convert to forestry activities. Thus the strategy for expansion becomes more complex, operating through political and economic blackmail that leaves no alternatives.

The rising economic incentive to massively expand tree plantations for cellulosic ethanol will only worsen the conflicts between communities who need land for food and companies who want the land to grow trees.

Another consequence of the rising emphasis on cellulosic ethanol as the next generation of biofuels technology is the accelerated promotion of fast-growing, easily digested, genetically engineered (GE) trees, which have been widely promoted as a future feedstock for cellulose-based ethanol. Additional genetic research is targeting oil palm and jatropha for greater and higher quality oil production for biodiesel, as well as future production of chemicals and plastics.

In the U.S., GE low-lignin poplar plantations for ethanol production are being proposed for "unused" agricultural land. A statement by Purdue University in the U.S. touts the possibilities:

> Researchers believe that using the hybrid poplar in its present form could produce about … 700 gallons of ethanol [per acre annually]. Changing the lignin composition could increase the annual yield to 1,000 gallons of ethanol per acre, according to experts. Planted on 110 million

> acres of unused farm land, this could replace 80 percent of the transportation fossil fuel consumed in the United States each year.

Besides greatly exaggerating the potential benefits of low-lignin trees, this statement encourages us to accept the widely peddled myth that any "unused" farmland is better suited to fueling motor vehicles in the U.S. than to feeding people or providing habitat for wildlife. It also ignores the tremendous quantities of water consumed by the manufacture of cellulosic ethanol and the impact this will have on communities and ecosystems. For every gallon of ethanol produced, about 4 gallons of water are used in the refinery process. A refinery producing 100 million gallons of ethanol per year therefore requires about 400 million gallons of water. Cellulosic ethanol, if it becomes feasible, will likely place even greater demands on water at a time when global supplies of freshwater are in serious decline.

GE Trees & Contamination of Wild Forests

Beyond the threats to food are the threats to forests. Richard Meilan, a faculty member at Purdue University, points out that "The genus *Populus* includes about 30 species that grow across a wide climatic range from the subtropics in Florida to subalpine areas in Alaska, northern Canada and Europe." While he makes this point to demonstrate the flexibility of the poplar as an energy crop, he also raises a serious red flag concerning the potential genetic contamination that could result from the commercial release of a GE tree that has such a large and widespread population of wild relatives. According to *The Economist*, countries like Sweden are also considering the use of GE poplars for cellulosic ethanol. Even the use of non-native tree species, such as GE eucalyptus in the southeastern U.S., raises serious concerns about the impacts that the escape of genetic material from GE trees could have on native forests.

Our understanding of the contamination potential from future plantings of GE trees is largely based on known contamination incidents from GE food crops and experimental plantings of engineered grasses. While there has not yet been a comprehensive study of crop contamination from GE varieties, several well-documented incidents have alerted the world to the seriousness of this problem. Two incidents of transgenic contamination of wild relatives have been studied in some detail: the transmission of an herbicide-tolerance gene from oilseed rape (canola) to weedy wild turnip hybrids in Canada and the detection of herbicide-tolerant grasses up to 21 kilometers from a test site in Oregon.

There have also been two attempts to systematically address the contamination potential of GE crops. Since 2005, Greenpeace, in collaboration with GeneWatch in the U.K., has maintained an online database of GMO contamination incidents, known as the GM Contamination Register. Their 2006 report lists 142 publicly documented incidents in 43 countries since the introduction of commercial GE crops in 1996. These include instances of contamination of food, seed, animal feeds and wild relatives of crops, as well as illegal releases of unapproved GE varieties and documented negative agricultural side effects. Also in 2006, the U.S.-based Center for Food Safety released a report on the contamination potential from field trials of new, experimental GE crop varieties, reviewing the prevalence of field trials of GMOs with known wild relatives across the U.S.

The incidents of contamination listed in the side box prove that gene escape and GE contamination cannot be prevented once GE crops are released. This in turn suggests that the widespread planting of GE trees would over time lead to a persistent contamination of the world's native forests, with disruptive, but as yet unknown ecological consequences.

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Unlike most crops, GE trees grown for agrofuels extraction are likely to be grown in the vicinity of genetically similar native and uncultivated tree populations. In China, GE insect-resistant poplars planted in 2001 were already found to be contaminating native poplars as early as 2004. Well-documented cases of GE contamination of wild relatives to crop plants are also of particular relevance.

In one example, herbicide tolerance genes from GE oilseed rape were found in a weedy wild turnip hybrid species in Canada, as well as in a sample of charlock, a weedy relative in the U.K. Charlock, a significant weed of oilseed rape, was previously believed to be incapable of spontaneous hybridization with domesticated rape varieties.

Further complicating the situation, several common weedy plants in agricultural regions in the U.S. have evolved resistance to the herbicide glyphosate (Roundup) as a result of continued exposure to Monsanto's "Roundup Ready" GE crop varieties. These include important weed species such as horseweed (marestail or *Conyza canadensis*), common ragweed (*Ambrosia artemisiifolia*), and rigid ryegrass (*Lolium rigidum*).

Also highly relevant to our understanding of the potential threat from GE trees is a carefully studied instance of native grass contamination from a test plot of creeping bentgrass genetically engineered for glyphosate resistance in Oregon. In 2004, researchers from the U.S. Environmental Protection Agency found numerous grasses within 2 kilometers of the experimental plot—as well as two samples 14 and 21 kilometers away—that were tolerant to glyphosate. Genetic analysis showed they contained one of the major components of the inserted DNA that imparts this trait. In a follow-up study two years later, researchers determined that the transgene had established itself in resident grass populations, as well as in a non-GE bentgrass that had been planted nearby as a monitor of potential gene flow.

With their investigation limited to publicly accessible areas within 310 square kilometers of the test plot, the researchers found nine established transgenic plants downwind "spread over an appreciable distance beyond the border of the control area." Through further DNA analysis, they determined that the contamination had been caused by a combination of pollen and GE seed dispersal. This is very significant, given the fact that glyphosate tolerance would not be particularly advantageous for plants outside the test zone. This study is also relevant to non-native GE tree species in biofuel plantations, since contamination was not only by pollen, but by seed as well.

What these studies reveal is the virtual impossibility of preventing contamination of native forests with pollen from native tree species that have been genetically engineered. The impacts of this contamination, however, would depend to a large extent on the traits involved, though the complexity of forest ecosystems makes it impossible to accurately predict the impact of any introduced trait. Nevertheless, irrespective of the specific traits, the genetic manipulation itself gives rise to risks. Several researchers have reviewed the ecologically disruptive character of genetic modifications in terms of gene expression, ecological fitness, and the production of potentially dangerous new metabolites, substances involved in the growth, development, and reproduction of organisms. In one brief review, Allison Snow of Ohio State University writes: "Although crops and weeds have exchanged genes for centuries, genetic engineering raises additional concerns because it not only enables introduction into ecosystems of genes that confer novel fitness-related traits, but also allows novel genes to be introduced into many diverse types of crops, each with its own specific potential to outcross." David Schubert of the Salk Institute also writes that "unintended consequences arising from the random and extensive mutagenesis caused by GE techniques opens far wider possibilities of producing novel, toxic or mutagenic compounds in all sorts of crops."

In a detailed analysis of over 200 published studies, researchers at EcoNexus in the U.K. documented significant increases in genetic instability, higher mutation rates, large-scale deletions and translocations of DNA, and other disturbing effects at the site of artificial gene insertion. There is no reason to believe these disruptions in gene expression will not also impact native tree species that become contaminated via cross-pollination with GE varieties.

Low-Lignin Trees

One genetic modification of particular concern for the earth's living ecosystems is genetic manipulation of trees for decreased lignin production. Biotech companies are pursuing engineering reduced-lignin trees for both agrofuels and paper production.

Lignin is an important structural polymer that also plays a significant role in the high levels of insect- and disease-resistance in trees. The very fact that lignin does not break down easily is essential to the resiliency of native tree species in the wild. Thus the consequences of a reduced-lignin trait spreading from agrofuel plantations to native forests could be severe and irreversible.

Fast-growing, reduced-lignin GE trees growing undetected in a native forest setting as the result of gene escape, might die off at an early age due to their inability to cope with environmental stresses. But even this scenario would be problematic. Because of their reduced lignin, these trees decompose more readily, rapidly releasing carbon and altering soil structure with unknown consequences for the soil ecosystem. Their faster growth at the seedling and sapling stage, however, could give them an evolutionary advantage over their non-modified cousins, resulting in a domination of GE low-lignin trees in the forest. How this will affect the forest ecosystem as it evolves is impossible to predict.

Low-lignin trees also have implications for the climate, according to the U.K.-based Institute for Science in Society:

> Aspen (*Populus tremuloides*) modified for reduced stem lignin had normal cellulose content accompanied by reduced lignin content. The transgenic aspen had reduced root carbon and greatly reduced soil carbon accumulation compared to unmodified aspen. The trees accumulated 30 percent less plant carbon and 70 percent less new soil carbon than unmodified trees. This makes the transgenic tree highly undesirable in terms of reducing carbon in the atmosphere, hence defeating the whole purpose of switching from fossil fuels to biofuels.

In addition to reducing the lignin in trees, biotech researchers are investigating altering the structure of lignin to enhance its digestibility to microbes. In one line of research, proteins are being introduced into plant cell walls to create protein-lignin linkages that could be digested using protease enzymes. In another scheme, researchers are looking at incorporating a particular plant protein called expansin into trees, as well as cellulase enzymes that would essentially enable the tree to begin to digest itself prior to harvest.

Once again, despite the dire threat of these traits escaping into forest ecosystems, assessments of the risks posed are not being done.

Disease and Insect Resistance

Because lignin naturally protects trees from insects and disease, trees with reduced lignin will probably have to be engineered with additional traits for disease and insect resistance, which creates additional concerns: connected to both the unintended side effects from stacking multiple genes into one organism, and to the potential escape of these genes. The U.K. research organization, The Corner House, notes that "trees genetically modified for resistance to disease are likely to cause fresh epidemics" by encouraging the survival of other diseases resistant to the genetic modification. Corner House researchers go on to assert that "fungicide production engineered into GM trees to help them counter such afflictions as leaf rust and leaf spot diseases may dangerously alter soil ecology, decay processes and the ability for the GM trees to efficiently take up nutrients…." Mycorrhizal fungus and other soil fungi are a critical part of forest ecology. As is true of the insecticide *Bacillus thuriengensis* (*Bt*) when it is engineered into plants, fungicides engineered into trees are likely to be exuded by the roots into the soil, killing beneficial soil fungi and damaging soil ecology.

Another significant concern is that the evolution of new, more pathogenic viruses may be accelerated by GE tree viral-resistance traits. Ricarda Steinbrecher elaborates on the potential for genetically engineered viruses to recombine with other viruses to create new and more deadly ones:

> The potential of such newly recombined viruses to overcome the defenses of related wild plants, or even be able to infect new host plants, is a serious concern. In laboratory experiments infecting viruses have also swapped their protein coat for that of another virus that had been engineered into a plant,...[and] the new coat enabled a virus to travel between plants, carried by aphids.

Insect resistance also presents serious concerns. In China, the problem of desertification was tackled through the planting of huge monoculture plantations of poplars. These poplars, however, fell victim to predation by caterpillars, and great numbers of them died. With the help of the UN Food and Agriculture Organization, genetically engineered insect-resistant poplars were then introduced. These GE poplars were engineered to produce *Bt* toxin, which targets the caterpillars of *Lepidoptera* (butterflies and moths). The project was started in 2002, and today more than 1 million GE poplars have been planted across ten provinces. However, no one knows exactly where they are. In 2004, the Nanjing Institute of Environmental Science reported that the *Bt* poplars were already contaminating native poplars, but it is not known how far this contamination has spread.

The escape of the *Bt* trait into native forests is problematic for numerous reasons. Insects have evolved with forest ecosystems for millions of years, and the ecological implications of eradicating certain species of insects has not been assessed. These impacts, however, are likely to be wide-ranging. For example, the insects targeted by *Bt* trees are an important food source for nesting songbirds, as well as other wildlife. At least one study has found that *Bt* toxin remains active and lethal after ingested and can make its way up the food chain and will actually bind to the intestines of non-target organisms, causing "significant structural disturbances and intestinal growths."

The fact that the *Bt* trait is expressed in every cell of the modified tree, including the pollen is a major concern in relation to pollinators such as bees and butterflies. As has been widely reported, bee populations in many regions throughout the world have recently experienced serious, and in some cases catastrophic, decline. Deployment of *Bt* trees on a large scale could further devastate pollinator populations. A new study released late in 2007 demonstrated that pollen and other plant tissues containing *Bt* toxins are washing into streams near cornfields, and that the *Bt* toxin is lethal to caddisflies, the most diverse order of aquatic insects and an important food source for fish and amphibians.

The leaching of *Bt* toxin from the roots of GE plants and into the soil can affect organisms present in the soil or the soil community as a whole. Thus it can impact beneficial soil microbe and pathogen interactions, nutrient cycling and uptake, and other poorly understood soil processes. Little is known about the way in which *Bt* toxin production alters the rotting process of dead *Bt* trees. Use of *Bt* toxin also raises concerns about the creation of "super-pests" and the killing of beneficial insects, as well as the displacement of insect pests from GE trees to more vulnerable species.

Beyond the impacts on forests and wildlife, however, are the impacts of *Bt* pollen on humans. Some studies suggest airborne *Bt* pollen may be toxic when inhaled, which could have serious ramifications for communities living close to GE tree plantations. Neither this potential health impact nor the long-term ecological consequences of the use of *Bt* trees have been adequately studied.

Genetically modified poplars used in biofuel plantations may also be engineered to become sterile. Proponents of genetic engineering claim that adding a sterility trait to GE trees would help prevent contamination of non-engineered trees. This argument is being used to attempt to reverse the moratorium on so-called "Terminator Technology." However, because of the complex nature of plant reproduction and gene regulation as well as the genetic changes trees experience as they age, it is highly unlikely that any sterility in trees can be reliably sustained. This means that contamination by seed or pollen would continue to be a threat. It also means there is the potential for stands of native trees themselves to become partially sterile through cross-pollination, or to become impaired in their development of flowers or seeds. Sterile trees would also be able to spread their transgenes through vegetative propagation.

Furthermore, the sterility modification itself has serious ramifications, primarily the likely impacts on native wildlife. Because sterile trees do not provide food (seeds, pollen, nectar) for insects, animals or birds, large monocultures of GE trees will displace a wide variety of native species. In addition, the trees themselves may be toxic.

Introduction of Non-Native Invasive Plants for Cellulosic Ethanol

Eucalyptus is the perfect neoliberal tree. It grows quickly, turns a quick profit in the global market and destroys the earth.

—Jaime Aviles, *La Jornada*

GE tree escape, via seed or vegetative propagation, is possible even from non-native species without wild relatives. The case of bentgrass contamination is instructive here, as it describes contamination resulting from seed dispersal. GE eucalyptus is one non-native tree being proposed by tree engineers as a potential feedstock for cellulosic ethanol plants.

Eucalyptus, native only to Australia, is a favorite species for pulpwood plantations worldwide. It is a notoriously invasive tree species that often out-competes native plant species. Eucalyptus was introduced in California in 1856, and is now widespread throughout the coastal and southern regions of the state. Because eucalyptus is also extremely fire-prone, California has spent millions of dollars trying to eradicate these invasive plants.

The Introduced Species Summary Project of Columbia University described the threat of eucalyptus to ecosystems in this way:

> The loss of biodiversity and habitat is a great threat from the … eucalyptus. It creates virtual monocultures and can rapidly take over surrounding compatible areas, completely changing the ecosystem. That monoculture creates a loss of habitats for many species that relied on the previous system. Due to its great capacity for taking over a wide variety of habitats, the … eucalyptus could possibly spread to a great range of systems where there is enough water content and create huge monocultures."

The U.S. Forest Service also reported concerns about the ability of eucalyptus to suppress the growth of other plants:

> The leaves of … eucalyptus release a number of terpenes and phenolic acids. These chemicals may be responsible for the paucity of accompanying vegetation in plantations. Natural fog drip from … eucalyptus inhibits the growth of annual grass seedlings in bioassays, suggesting that such inhibition occurs naturally. At least one leaf extract has been shown to strongly inhibit root growth of seedlings of other species.

In addition, a recent study has found that in elevated levels of CO_2 pollution, the leaves of eucalyptus have increased levels of toxicity, making them an even greater threat to ecosystems and wildlife.

While eucalyptus has been a favorite species for monoculture tree plantations throughout the tropics and subtropics, their temperature requirements have made other cooler climates, as well as higher altitudes, off limits. The company ArborGen, however, is currently engineering eucalyptus for cold tolerance so that it could survive at temperatures as low as -20ºC, which would greatly expand its potential range. This transformation of eucalyptus into a species that can survive in colder climates creates significant threats to forests in those climates. Extending the range of eucalyptus makes it possible for companies to replace slower-growing (but carbon rich) native forests with fast-growing (but carbon poor) eucalyptus plantations, which are considered more valuable for the production of cellulosic ethanol. In his 2006 year-end report to stockholders, Rubicon CEO Luke Moriarty alludes to the economic potential of the cold-tolerant GE eucalyptus: "The excellent results of the best performers in the field trials would suggest that the level of cold tolerance can be extended even further, thus offering a broader geographic market for this new hardwood product than originally anticipated."

Besides wiping out native forests for eucalyptus plantations, the commercial use of cold-adapted eucalyptus could result in the escape of these GE trees (via seed or asexual vegetative reproduction) into ecosystems and forests where they could out-compete native vegetation and displace wildlife. Furthermore, the southern U.S., where establishment of commercial GE eucalyptus biofuel feedstock plantations is being promoted by ArborGen, is known to be subject to strong storms, including tornadoes and hurricanes, which have the potential to distribute eucalyptus seeds over areas from tens to hundreds of kilometers.

Development of second generation biofuels in Brazil is also a concern. Efforts are currently focusing on the use of bagasse—the biomass left over from the production of sugar cane-based ethanol. Denmark-based Novozymes is cooperating with Centro de Tecnologia to develop facilities to utilize all parts of the sugarcane plant for ethanol production. Novozymes CEO Steen Riisgaard explained, "the research agreement is part of our efforts to identify economically profitable processes within the development of biofuels from plant waste and other biomass." While these facilities may be developed under the guise of reducing "waste" in the production of ethanol, they are also a step towards the acceptance of other cellulosic feedstocks as well. In Brazil, these future feedstocks include GE low-lignin eucalyptus.

ArborGen is already developing GE low-lignin eucalyptus in Brazil, as is pulpwood giant Aracruz Cellulose, and there are twenty-one outdoor field trials already underway in Brazil. The construction of cellulosic ethanol refineries in Brazil opens up another huge market for GE reduced-lignin trees, and ArborGen foresees millions of dollars in profits from the sale of its GE low-lignin eucalyptus pulp, due to the fact that the company expects it to be more valuable than conventional eucalyptus pulp since it is less expensive to process than eucalyptus with normal levels of lignin. Eucalyptus is already a serious problem in Brazil, where plantations have replaced vast stretches of the *Mata Atlantica* coastal forest ecosystem. Increasing demand for eucalyptus for cellulosic ethanol and paper pulp, will necessitate expansion of eucalyptus plantations and create pressure to commercialize GE low-lignin eucalyptus, further threatening ecosystems like the *Mata Atlantica* and the *Amazon*. In fact, Brazil has announced a scheme to "reforest" the Amazon with up to 25 million hectares of eucalyptus plantations. Given Brazil's vehement opposition to any restrictions on planting of genetically engineered trees at the May 2008 Convention on Biological Diversity, there is no reason to believe these eucalyptus would not be genetically engineered.

The destructive nature of eucalyptus led Mexico's *La Jornada* journalist, Jaime Aviles, to call eucalyptus "The perfect neoliberal tree," noting that it "grows quickly, turns a quick profit in the global market and destroys the earth."

GE Jatropha and Oil Palm

Beyond genetically engineering trees for cellulosic ethanol production, biotech researchers are also exploring ways to engineer Jatropha and oil palm trees so that their oil-bearing seeds produce better biodiesel, as well as other oil-based products.

African oil palm is native to tropical Africa, where it grows from the Congo to Sierra Leone, while American oil palm is native to Central and South America. However, both of these species are now widely cultivated in tropical areas around the world. Jatropha is native to Central America and the Caribbean, and it too is being cultivated or planned for cultivation in huge monocultures in India, China, Africa, Latin America and elsewhere.

The giant multinational oil corporation BP is investing US$76 million in Jatropha cultivation. India has identified 11 million hectares of land for future jatropha plantations. China is moving forward with plans for more than 13 million hectares of jatropha and other biofuel feedstocks on sensitive, biologically rich native forestlands in southwestern China. In Western Australia, however, Jatropha has been banned due to the fact that it is extremely invasive and highly toxic to animals and people (ingesting three untreated seeds can be fatal to humans).

Scientists are engineering these two trees for a variety of traits. Oil palm is being modified in Indonesia and Malaysia to change the composition of its oil. Food industry researchers are seeking to modify it for reduced saturated fatty acid content. Others are working to make the oil adaptable to new uses, for example, as a source of biodegradable plastics and other products currently manufactured with petrochemicals. They also want to increase the oil content of the seeds. Because of its susceptibility to some insects, oil palm is also being engineered for insect resistance (with all of the potential consequences previously mentioned). It is also being engineered for resistance to the herbicide glufosinate. Companies are also moving toward genetically engineering Jatropha to increase production and improve the oil content of the seeds.

Conclusion

The pursuit of a global energy strategy that features wood as a major agrofuel feedstock clearly poses a variety of potential problems. Use of genetically engineered trees for agrofuel production would significantly increase this risk, with serious implications for the world's forests and forest-dependent peoples.

In the U.S. for example, efforts are underway to transform the monoculture loblolly pine plantations of the Southeast U.S. from the world's main source of paper pulp to the primary feedstock for cellulosic ethanol production in the region. A company called Range Fuels is developing an ethanol production facility specifically for this purpose with funds from the U.S. Department of Energy. Georgia has been quoted as seeking to become the "Saudi Arabia of biofuels," using its pine plantations as the feedstock.

Taking these pine plantations out of paper production and transitioning them into ethanol production will have global implications. As the raw materials to feed the world's increasing appetite for paper are no longer available from existing plantations, pressure on the world's remaining forests to supply this need will increase. In addition, the rapidly rising demand for wood, triggered by cellulosic ethanol production, will accelerate the conversion of native forests into fast-growing monoculture tree plantations and escalate rates of illegal logging. This skyrocketing demand for wood will also further the pressure to commercially develop genetically engineered tree plantations, which will in turn threaten the ecological integrity of remaining native forests.

With current rates of deforestation contributing 20 percent of global carbon emissions annually, the massive increase in deforestation that will accompany the rise of wood-based ethanol production will have significant impacts on climate, belying the argument that cellulosic ethanol will be part of the solution to global warming. Consequently, the massive increase in logging and the planned use of genetically engineered trees that will accompany the production of wood-based "second generation" agrofuels make this so-called "alternative energy" one of the foremost threats to forests and forest-dependent peoples across the globe.