

An aerial photograph of a vast, dense forest landscape. The forest is a mix of green and brown, suggesting some deforestation or seasonal changes. The horizon is hazy, and the sky is filled with large, white, fluffy clouds. The overall scene is a wide, panoramic view of a natural environment.

AN IMPENDING STORM

IMPACTS OF DEFORESTATION ON WEATHER PATTERNS AND AGRICULTURE

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Greenpeace Research Laboratories
Technical Report (Review) 04-2013

GREENPEACE

AN IMPENDING STORM

Impacts of deforestation on weather patterns and agriculture

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EXECUTIVE SUMMARY



Open flames on dry tree branches in an area of recently deforested peatland in the PT Rokan Adiraya Plantation palm oil plantation near Sontang village in Rokan Hulu, Riau, Sumatra.
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Forests currently cover around 30% of the Earth's land surface, but are being lost at an "alarming rate" (FAO, 2010). Deforestation is highest in the tropical areas of South America, central West Africa, and South and Southeast Asia, with 13 million hectares of global forest lost each year (FAO, 2010). Forests provide ecosystem services that include the regulation of weather and climate at local, regional and even global levels. Therefore, deforestation not only causes a direct loss of forest habitat but also leads to indirect impacts as ecosystem services deteriorate or fail. While it is well known that deforestation emits carbon dioxide that contributes to global climate change, less well known are the projected impacts on weather patterns. This report reviews published studies on these indirect impacts of deforestation and their potential impact on agriculture.

Changes in land cover (for example, conversion of forest to crop land) affect the exchange of moisture and heat between the soil, vegetation and atmosphere; altering natural cycles and changing atmospheric circulation. This leads to changes in local and regional surface temperatures and also rainfall patterns. Local changes in atmospheric circulation caused by deforestation can, potentially, affect weather patterns on the other side of the world. Teleconnection is an emerging scientific concept that links changes in atmospheric circulation and pressure patterns across the world over large distances. Remote areas are indirectly impacted by deforestation due to the propagation of impacts through global teleconnections. The El Niño-Southern Oscillation is one example of a teleconnection, where warmer ocean temperatures result in changes to climate patterns over large geographic areas.

Projecting the indirect effects of deforestation on weather and climate is an emerging area of science. Inherent uncertainties exist with modelling of complex environmental systems, so projected effects and impacts contain a degree of uncertainty, with phrases such as "may affect" being used to convey this. Despite this uncertainty, many models show wide scientific consensus that deforestation has the potential to disrupt weather and climate systems on a local, regional and global scale. Further studies will undoubtedly increase our understanding of the indirect impacts of deforestation.

The major global indirect impacts projected from deforestation are changes to rainfall patterns and surface temperatures. A reduction in evapotranspiration and moisture circulation is indicated to weaken the hydrological cycle, with models suggesting up to 80% reduction in annual rainfall in deforested areas (Hasler *et al.*, 2009). In certain regions, surface temperatures are predicted to increase by a maximum of 3°C, using complete deforestation models (Snyder, 2010). This is largely due to the reduction in evaporative cooling associated with vegetation loss (Snyder, 2010). However, boreal deforestation could decrease northern hemisphere temperatures due to cooling effects associated with increased snow cover. Changes to rainfall and surface temperatures are expected to impact agriculture and crop harvests, with an approximate 10% reduction in crop yields for a 1°C rise in temperature (Lobell *et al.*, 2011).

Other potential impacts include poor air quality and the spread of diseases. In Southeast Asia, smoke from fires associated with deforestation, particularly of peat forests, adds considerably to existing urban air pollution, especially in El Niño years (Johnston *et al.*, 2012; Marlier *et al.*, 2013). Modelling attributes an average of 110,000 deaths a year in the region to these fire emissions, primarily long-term seasonal exposure to smoke particles, rising to 300,000 deaths during the 1997/8 El Niño year (Johnston *et al.*, 2012). Diseases such as malaria and yellow fever may spread due to the removal of forest pathogen hosts, increases in standing water, and faster reproduction cycles caused by warmer temperatures (Vittor *et al.*, 2006; Patz *et al.*, 2008). Forest removal is also linked to increased flood risk and surface run-off (Bradshaw *et al.*, 2007).

The end use of much deforested land is agriculture. Deforestation for agriculture – as well as having extremely negative impacts from a climate change and biodiversity perspective – increasingly appears to be counterproductive if it leads to changes in weather and climate systems that impact agricultural production. Voldoire & Royer (2004) suggest that deforestation could cause more intense climatic extremes, which would result in larger negative impacts to agriculture than those associated with temperature increases due to climate change. For example, their model indicates that El Niño years would be drier than present, increasing soil water stress and reducing evaporation. Modelling suggests that loss of forests in areas such as Amazonia and Central Africa can severely reduce rainfall in the US Midwest at times when water is crucial for agricultural productivity in these regions (Avisar & Werth, 2005).

Modelling is currently the best tool to investigate differences in deforestation extent, as well as covering both regional and global areas¹. These studies tend to model complete deforestation to maximise effects on climate and weather, although expected impact trends associated with both current and historical deforestation are also indicated. Importantly, indirect impacts may act in a non-linear fashion. That is to say, instead of a steady change, there may be little noticeable effect for a period but then a rapid change to different conditions occurs when a “tipping point” is reached.

Deforestation for agriculture – as well as having extremely negative impacts from a climate change and biodiversity perspective – increasingly appears to be counterproductive if it leads to changes in weather and climate systems that impact agricultural production.

¹ Computational models are used to predict the impacts of deforestation as widespread destruction of forested areas for a scientific purpose is both unfeasible and undesirable.

In conclusion, there is wide scientific consensus that deforestation can cause indirect impacts to local and regional weather systems, such as rainfall patterns and surface temperatures. There is also strong modelling evidence for remote global impacts via teleconnections caused by deforestation in the three main tropical forested areas (Amazon, equatorial West Africa and Southeast Asia). These impacts vary in extent and magnitude, but there is agreement on deforestation being the underlying cause.

Ending deforestation would stop the direct loss of forest habitat but it would also minimise the indirect effects of deforestation and the possibility of changes to weather and climate systems, locally, regionally and globally. There would also be benefits to public health, reductions in flood risks, and decreases on the negative impacts on crop output in certain areas. Our knowledge of the services provided to humans by forest ecosystems (underpinned by biodiversity) is incomplete, and hence the full consequences of their loss cannot be estimated with any certainty. Therefore, employing the precautionary principle and conserving existing forest ecosystems under a “Zero Deforestation” footprint is the only way to ensure that forests continue to regulate our weather and climate, minimise the indirect effects of deforestation and conserve biodiversity.

Indirect impacts of Asian deforestation²

Rainfall: Southeast Asia is modelled to have a 1mm/day decrease in rainfall throughout the year if forest cover loss is complete (Werth & Avissar, 2005a), with southern China and Vietnam undergoing a 20-30% decrease in rainfall (Sen *et al.*, 2010).

Temperature: Models indicate a regional increase in air temperature of 1°C after complete deforestation (Schneck & Mosbrugger, 2011).

Monsoons: It was suggested that the East Asian monsoon flow would weaken over eastern China and the South China Sea, but become enhanced over mainland Southeast Asia after complete deforestation (Sen *et al.*, 2004; Sen *et al.*, 2010).

Oceans: Surface temperatures could reduce by up to 1.25°C in the Southern and South Indian Oceans, but increase by 0.75°C in the South Pacific Ocean after complete deforestation, impacting ocean circulation (Schneck & Mosbrugger, 2011).

Coastal protection: Removal of mangrove forests increases community exposure to ocean and tidal influences such as cyclones and tsunamis (Kathiresan & Rajendran, 2005)

Human health: Smoke from fires associated with deforestation, particularly of peat forests, adds considerably to existing urban air pollution in Southeast Asia, especially in El Niño years (Johnston *et al.*, 2012; Marlier *et al.*, 2013). This can affect people's health, not only in the immediate vicinity, but also in urban centres near forest burning.

Teleconnections: A 20-25% decrease in rainfall in western Turkey (Avissar & Werth, 2005), enhanced storm track activity over Scandinavia (Snyder, 2010), changes to European storm track locations (Snyder, 2010), cooling in Siberia of 1°C, and increased temperatures in Canada and central Africa, are all suggested as consequences of complete Asian deforestation (Schneck & Mosbrugger, 2011).

Employing the precautionary principle and conserving existing forest ecosystems under a “Zero Deforestation” footprint is the only way to ensure that forests continue to regulate our weather and climate, minimise the indirect effects of deforestation and conserve biodiversity.

² These modelled impacts focus on deforestation impacts only, so are separate from those expected due to global climate change. Model results are independent of changes caused by increases in greenhouse gas concentrations.

Indirect impacts of African deforestation

Rainfall: Modelling suggests widespread reductions in rainfall of 1mm/day locally (Werth & Avissar, 2005b), with a 2-3mm/day decrease in the dry season (Semazzi & Song, 2001) after complete tropical African deforestation. These models showed regional patterns; Mozambique would experience reduced rainfall, while Botswana, Zambia and the southern Democratic Republic of Congo would experience increased rainfall.

Temperature: Land surface temperatures were indicated to increase locally between 1.2-2.4°C following complete deforestation of South Sudan (Salih *et al.*, 2012).

Monsoons: The West African monsoon weakens due to reduced northward moisture transport after modelled loss of West African forests (Abiodun *et al.*, 2008).

Agriculture: Western Kenyan agriculture production was expected to reduce following decreased rainfall linked to local forest loss (Otieno & Anyah, 2012).

Teleconnections: Models of complete forest loss in central Africa suggest a 5-35% rainfall decrease in the US midwest (Avissar & Werth, 2005), which could impact crop harvests and global food supply. The Arabian Peninsula was expected to have a 15-30% increase in rainfall (Avissar & Werth, 2005).

Indirect impacts of Amazon deforestation

Rainfall: Annual rainfall is modelled to decrease by 10-20% across the entire basin after total Amazon deforestation (Moore *et al.*, 2007), but there are some regional differences. The northwest of the basin is predicted to become drier by up to 2mm/day, while the southeast may become wetter by up to 1.5mm/day (Medvigy *et al.*, 2011).

Flood risk: Annual discharges into a river in the southeast of the Amazon have increased by 25% following land use change (forests to agriculture) over the past 40 years (Costa *et al.*, 2003), and flood risks are considered to have increased (Davidson *et al.*, 2012).

Temperature: Modelling complete conversion of Amazonian forest to agriculture suggests significant temperature increases locally of around 2°C (Feddema *et al.*, 2005). The frequency of extreme cold events is indicated to triple in the south and west of South America, which would impact agriculture (Medvigy *et al.*, 2012).

Agriculture: Reductions in rainfall and increased extreme cold events would negatively impact crops such as coffee, maize, soybean and wheat (Medvigy *et al.*, 2012).

Teleconnections: With complete deforestation of the Amazon, rainfall is suggested to decrease by 25% in Texas, but increase by 45% in the Arabian Peninsula (Avissar & Werth, 2005). At the same time, Northern Europe would also experience increased annual rainfall (Feddema *et al.*, 2005).

1. INTRODUCTION



Areas of natural forest in the southwest of Cameroon are being cleared to establish a large-scale palm oil plantation, despite growing local and international opposition and a heightened risk of social conflict over the project.

© Greenpeace / Alex Yallop

The worldwide forest area is around 4 billion hectares, approximately 30% of the Earth's land surface, but it is declining by 13 million hectares a year – an “alarming rate” (FAO, 2010). Deforestation is highest in the tropical regions of South America, central West Africa and South and Southeast Asia. Forests provide ecosystem services that include the regulation of weather and climate at local, regional and global levels. Therefore, deforestation not only causes a direct loss of forest habitat but also leads to indirect impacts as ecosystem services fail. While it is well known that deforestation emits carbon dioxide that contributes to global climate change, less well known are the projected impacts on weather patterns. This report reviews published studies on these indirect impacts of deforestation and their potential impact on agriculture.

A change in land cover impacts the exchange of water and energy between the soil, vegetation and the atmosphere. These changes can alter atmospheric circulation and thermodynamics, affecting rainfall patterns and surface temperatures (Foley *et al.*, 2003). Local and regional climate may be impacted by these changes in land cover, with evidence for global climatic changes in distant regions due to atmospheric teleconnections (Snyder, 2010). Teleconnections are processes that link changes in atmospheric pressure and circulation patterns across the world, despite large distances. One example of a teleconnection is the El Niño-Southern Oscillation (Snyder, 2010). Tropical land areas influence climate³ in mid-latitude regions, since they are a major energy source to the atmosphere. General atmospheric circulation transports this energy towards the poles to maintain the global energy balance. Changes to the tropical energy balance and this northwards transport process could lead to impacts on the climate in northern latitudes (Snyder, 2010).

3 The distinction between deforestation impacts on weather and/or climate is unclear so this report has referred to the terminology as used within each study. The implications of deforestation on carbon storage and hence climate change are not covered here.

Many components of the Earth system can display non-linear behaviour (Lenton *et al.*, 2008). The ecosystem goods and services provided by forests, such as the regulation of climate and rainfall, might also exhibit non-linear behaviour. That is to say, instead of a steady decline in an ecosystem service, there may be little noticeable effect for a period but then a sudden change to a different state occurs; in this case, one where that ecosystem service would no longer be provided.

The concept of non-linearity is best illustrated by “tipping points”. In the Amazon basin, the combined effects of deforestation and global climate change threaten to push the forest towards a “tipping point” (Lenton *et al.*, 2008; Malhi *et al.* 2009). It is suggested that 40% deforestation of the Amazon basin might be enough for it to reach a tipping point, after which an irreversible drier climate would establish preventing reforestation (Sampaio *et al.*, 2007; Nobre & Borma, 2009). Similar tipping points have not been reported for other large tropical forested areas (e.g. Southeast Asia or the Congo Basin).

Models are used to predict the impacts of deforestation. They can investigate differences in deforestation extent, as well as cover both regional and global areas. Indirect impacts can be hard to identify, due to natural climate variability (Findell *et al.*, 2006) and the difference between time scales of observations (days) and modelled (years) systems (Aragão, 2012). However, as widespread destruction of forested areas for a scientific purpose is unfeasible, modelling is currently the best tool. This field is an emerging area of science with further studies expected. Importantly, although many of the models project the consequences of total deforestation in a specific region, they give an idea of what trends might be expected, for example in terms of rainfall or temperature. However, this does mean any steady transition would occur, as the system may well respond in a non-linear fashion. Most models in this report study complete deforestation, so figures are reported for impacts linked to total forest cover loss. Where this differs, it is noted in the text.

This report identifies indirect impacts associated with deforestation, and investigates the impact these may have on agricultural production and weather patterns. Studies specific to indirect impacts associated with deforestation in the Amazon, Asia, Africa and the Boreal forest are also noted.

2. INDIRECT IMPACTS OF DEFORESTATION



Thousands of peatland fires in Riau, Sumatra - the majority within pulp and palm oil concessions - have caused record-breaking air pollution in Singapore and Malaysia, with the haze extending as far as Thailand.
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Human health

Fire emissions

Together with burning of savannah, forest fires make up most of the smoke from landscape fires globally. Forest fires do occur naturally in some types of forests, but typically not in tropical rainforest. However, degradation of rainforests increases their vulnerability to fire, and burning is often used to clear forests. In Southeast Asia, forest clearance fires associated with deforestation, especially of peat forests, are the primary source of fire emissions in the region (Johnston *et al.*, 2012). They add considerably to existing urban air pollution, particularly in El Niño years when drought increases the extent and longevity of fires (Johnston *et al.*, 2012; Marlier *et al.*, 2013). This smoke includes carbon particles smaller than $2.5 \mu\text{m}$ in diameter (PM_{2.5}), which are harmful to human health. Gases from fires also contribute towards low-level ozone formation.

During strong El Niño years, modelling indicates that particulates from landscape fires alone cause World Health Organisation (WHO) daily PM_{2.5} guidelines to be exceeded in the worst affected areas of Southeast Asia by between 100 and 200 days a year (Johnston *et al.* 2012; Marlier *et al.* 2013). In the models, average particulate levels from fires alone exceed WHO annual PM_{2.5} guidelines over large parts of the islands of Borneo and Sumatra and also Peninsular Malaysia. Johnston *et al.* (2012) estimate that 110,000 deaths a year (average 1997-2006) are attributable to fire emissions in the region, primarily long-term seasonal exposure to smoke particles. This rises to nearly 300,000 deaths during the 1997/8 El Niño year. Marlier *et al.* (2013) modelled the health impact of fire emissions in Southeast Asia (1997-2006) in terms of increase in mortality from cardiovascular disease. The increased annual mortality was approximately 10,800 adults (a 2 % increase) from exposure to PM_{2.5}, and a further 4,100 adults from exposure to ozone.

There are high population densities near to high fire activity areas in Southeast Asia, and this enhances the health impact of fire emissions in this region (Marlier *et al.*, 2013). Both studies recommend that reductions in exposure to fire emissions via decreases in deforestation would have an immediate and measurable effect on human health, as well as preserving the forest ecosystem.

“Reducing fires [in SE Asia] from deforestation and land management would benefit public health in addition to global scale benefits for carbon storage and biodiversity.”

– Marlier *et al.*,
2013

Disease

Deforestation could increase the risk and spread of disease, due to increased contact with wildlife and the destruction of existing pathogen forest hosts. In particular, forest clearance increases artificial water pools that can become breeding sites for malaria-carrying mosquitoes. Vittor *et al.* (2006) report that changes in malarial disease patterns have been recorded due to deforestation in the Amazon. Sites that were 80% deforested had a mosquito (*Anopheles darlingi*) biting rate that was 278 times higher than the rate in areas which had less than 30% deforestation. It is thought that this is due to *A. darlingi* breeding preference for grass or crop land. In Kenya, open, treeless habitats have a warmer midday temperature than forested areas. The increase in temperature shortened the reproductive cycle of the female mosquito *Anopheles gambiae* by 52% during the dry season (Patz *et al.*, 2008). These studies show it may be possible for deforestation to increase mosquito populations, and thereby the transmission of diseases such as malaria.

There are also concerns that diseases such yellow fever and dengue could re-emerge in some countries, or increase their outbreak frequency (Walsh *et al.*, 1993). Grard *et al.* (2011) raised concerns that Crimean-Congo haemorrhagic fever virus could re-emerge in Africa, following increased dry savannah habitats possibly caused by deforestation.

Hydrological cycle

Forests are a vital constituent of the global water cycle, as they have a high evaporation rate, contributing to atmospheric moisture circulation. Aragão (2012) reports that the forest canopy recycles water more efficiently through evapotranspiration than sparsely vegetated surfaces such as crop fields. Evapotranspiration is the combination of evaporation and transpiration from vegetation to the atmosphere. Deforestation weakens the local hydrological cycle, and a new pattern of heat release occurs due to the changed land cover (Figure 1). This heat release change propagates around the world via teleconnections, affecting the global pattern of rainfall (Werth & Avissar, 2005b).

Rainfall

Deforestation can reduce evapotranspiration due to a loss of vegetation. This results in reduced moisture circulation and decreased rainfall (Spracklen *et al.*, 2012). Deforestation also impacts local thermodynamics, resulting in a decrease in heat released to the atmosphere. This impacts atmospheric circulation and its associated rainfall (Avissar & Werth, 2005). Models suggest that deforested regions have reduced annual rainfall of up to 80%, with regions outside of the deforested area also impacted by rainfall changes (Hasler *et al.*, 2009; Figure 2). Spracklen *et al.* (2012) suggest that large-scale land-use change could alter rainfall patterns hundreds to thousands of kilometres away from the region of deforestation. Changes to rainfall patterns could result in droughts, especially in the dry season, negatively impacting agriculture and water availability.

“Unabated loss of forests may increase or exacerbate the number of flood-related disasters, negatively impact millions of poor people, and inflict trillions of dollars in damage in disadvantaged economies over the coming decades.

This first global-scale empirical demonstration that forests are correlated with flood risk and severity in developing countries reinforces the imperative for large-scale forest protection to protect human welfare, and suggests that reforestation may help to reduce the frequency and severity of flood-related catastrophes.”

*– Bradshaw et al.,
2007*

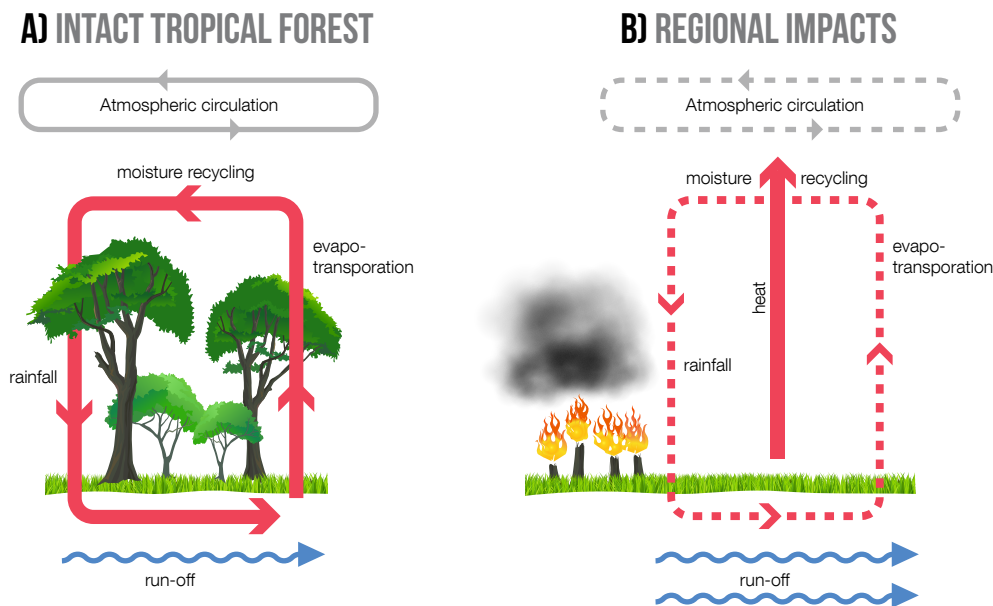


Figure 1: Intact tropical rainforest (A) recycles moisture and has low run-off. Regional impacts of tropical deforestation (B) include human health issues associated with smoke from fire clearance, spread of disease (for example, malaria), increased run-off and flood risk, increased temperatures, and reduced rainfall due to decreased moisture recycling. These changes alter atmospheric circulation. After Aragão, 2012.

Flooding

Loss of forests can lead to increased water run-off, as there is limited interception of rainfall and reduced evaporation of water from the canopy (Bradshaw *et al.*, 2007). Spracklen *et al.* (2012) suggest that decreased evapotranspiration due to deforestation could increase localised run-off and raise river levels. These impacts could contribute towards flooding, especially in the wet season. Bradshaw *et al.* (2007) report that flood frequency was negatively correlated with the amount of remaining forest, but positively correlated with the amount of forest area lost. Modelling indicates that a 10% decrease in natural forest area results in an increased flood frequency between 4% and 28%, depending on the country being modelled. The same 10% decrease in forest cover also results in a 4-8% increase in total flood duration.

Temperature

It is thought that global deforestation would have a regional cooling effect in temperate and boreal zones of the northern hemisphere, but a regional warming effect in the tropics (Davin & Noblet-Ducoudré, 2010). Lee *et al.* (2011) expand upon this theory, stating that their models indicate that north of 45° latitude there is increased cooling, and south of 35° latitude there is some evidence of increased warming. Deforestation results increase temperatures due to the reduction in the cooling effects of evapotranspiration caused by loss of vegetation (Snyder, 2010). This also contributes towards reduced cloud formation (Castillo & Gurney, 2012).

Models by Snyder (2010) indicate that deforestation in all three major tropical forest centres would cause increased air temperatures within the forest regions of 2- 3°C. For example, the Amazon region is predicted to warm by 1.88°C between September and November. The surrounding oceans are thought to limit the temperature response in Southeast Asia. Regions outside of the deforested areas are shown to warm, particularly southern Siberia and China, due to global teleconnections and amplification of changes to northern hemisphere circulation. Albedo-driven cooling is an important mechanism in boreal regions (Davin & Noblet-Ducoudré, 2010). Albedo is a measure of surface reflectance, so as forest clearance exposes highly reflective snow (high albedo), warming radiation is reflected instead of absorbed. This contributes towards cooling of surface temperatures and expansion of snow cover, resulting in net cooling (Spracklen *et al.*, 2008).

Agriculture

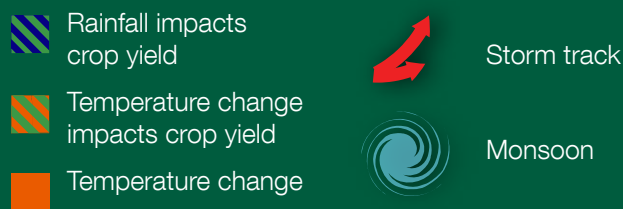
The end use of much deforested land is agriculture. Deforestation for agriculture may be counterproductive if deforestation leads to changes in weather and climate systems that impact agricultural production. Voltaire & Royer (2004) suggest that deforestation could cause more intense climatic extremes that would result in larger negative impacts to agriculture than those associated with temperature increases due to climate change. For example, their model indicates that El Niño years would be drier than present, increasing soil water stress and reducing evaporation.

Lobell *et al.* (2011) report that a 1°C rise in temperature as a result of global climate change generally lowered crop yields by 10%, except at high latitudes where crops benefit from warmer temperatures. They also note that rainfall increased yields for almost all crops but a point does occur where further rain starts to cause damage. In Sub-Saharan Africa, models predict decreases in the five main crop yields (maize, sorghum, millet, groundnut and cassava) with climate warming, despite predicted increases in rainfall in east Africa (Schlenker & Lobell, 2010). Models of land change from native woody vegetation to agricultural land in Australia indicate that it caused a decrease in rainfall and an increase in temperature in southeast Australia. This area of Australia is a major agricultural producer, so these changes would lead to impacts on crop harvests (McAlpine *et al.*, 2007). These studies indicate that changes in temperature due to deforestation would adversely impact crop yields, affecting agriculture dependant economies and cattle feed.

“Changes in regional climate could exacerbate drought-related tree mortality, which in turn would reduce carbon stocks, increase fire risk and lower biodiversity. Such changes might also directly threaten agriculture, which generates \$15bn US dollars per year in Amazonia, and the hydropower industry, which supplies 65% of Brazil’s electricity. Society should therefore take urgent action now, to curb tropical deforestation and avert future environmental problems.”

– (Aragão, 2012)

Figure 2: Predicted impacts of deforestation on weather patterns and crop yields around the world: results from computer modelling studies.



Europe

Deforestation in Asia could lead to changes in European storm track location and intensity (Snyder, 2010), while Amazon deforestation may increase annual rainfall in northern Europe. This could impact crop yields.

Turkey

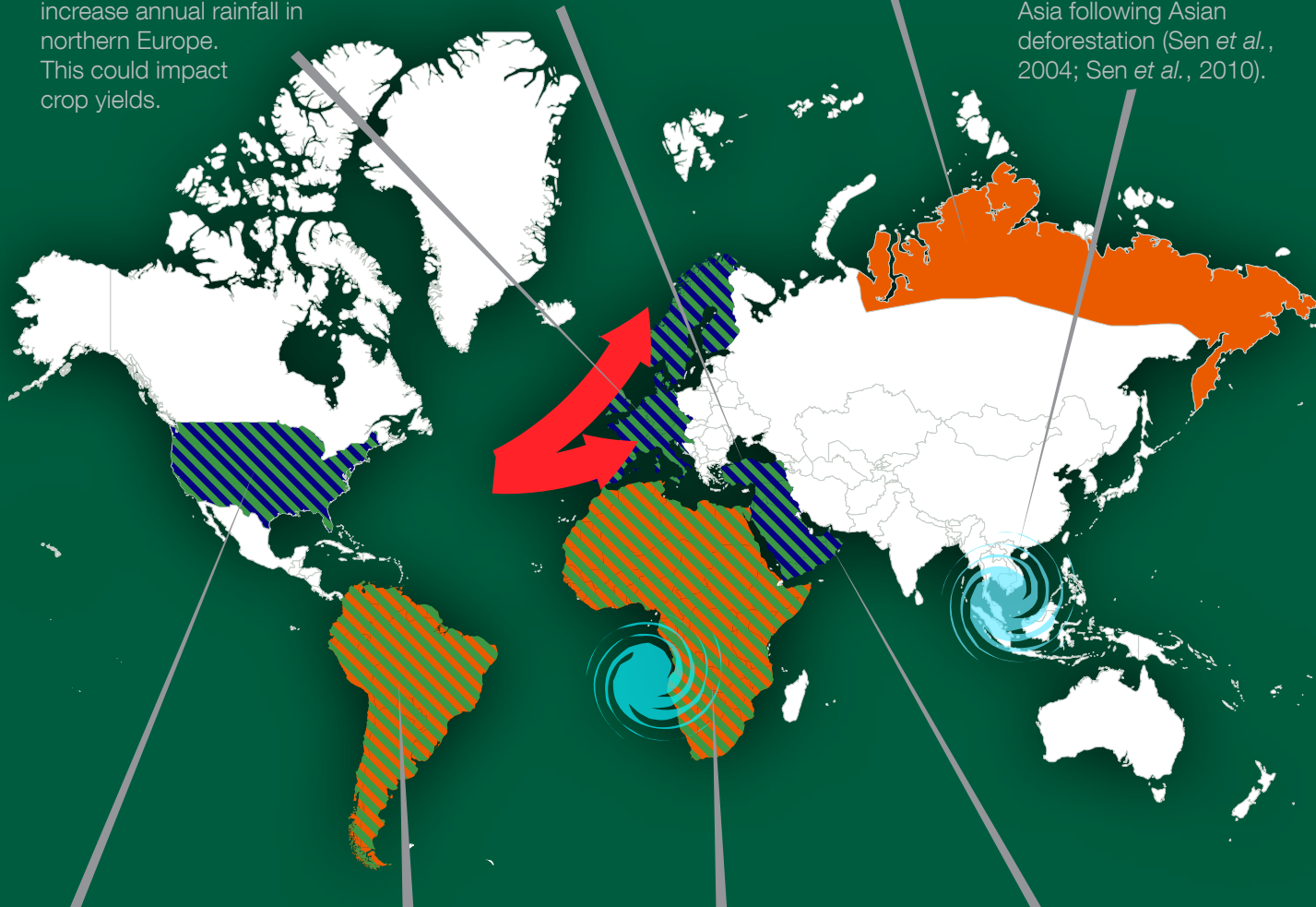
20-25% decrease in rainfall in western Turkey could occur due to southeast Asian deforestation (Avissar & Werth, 2005). This could impact crop yields.

Siberia

Temperature decrease of >1°C possibly due to Asian deforestation (Schneck & Mosbrugger, 2011).

Asia

The East Asian monsoon flow was suggested to weaken over eastern China and the South China Sea, but was enhanced over mainland southeast Asia following Asian deforestation (Sen *et al.*, 2004; Sen *et al.*, 2010).



USA

A 5-35% rainfall decrease in Midwest USA was linked to African deforestation, which is likely to impact crop harvests. A 25% decrease in rainfall in Texas was suggested after Amazon deforestation (Avissar & Werth, 2005).

South America

Temperature increase was related to Asian deforestation (Schneck & Mosbrugger, 2011). This could impact crop such as wheat, maize, soybean and coffee (Medvigy *et al.*, 2012).

Africa

Increased surface temperatures were associated with Asian deforestation (Schneck & Mosbrugger, 2011). The West African monsoon was indicated to weaken due to reduced northward moisture transport (Abiodun *et al.*, 2008). This could impact crop yields and increase water stress.

Arabian Peninsula

Rainfall was predicted to increase by 15-30% following African deforestation, or increase by 45% following Amazon deforestation (Avissar & Werth, 2005). This could impact crop yields.

3. INDIRECT IMPACTS OF ASIAN DEFORESTATION



Charred sapling and burnt stumps in recently cleared peatland forest area in Indragiri Hulu, Riau.
© Kemal Jufri / Greenpeace

Asia contains 15% of the global forest area (FAO, 2010), but is considered to have more complex impacts due to deforestation than those in the Amazon. This is due to the influence of the Asian monsoon, island geographic distributions, and different spatial features (Mabuchi *et al.*, 2005). Schneck & Mosbrugger (2011) report that models of Asian deforestation indicate changes to the regional hydrological cycle, warming of surface temperatures, and alteration of regional circulation patterns such as monsoons. The region's location within the warm west Pacific Ocean is likely to lead to strong ocean-atmosphere feedbacks resulting in regional and global climate impacts via teleconnections (Schneck & Mosbrugger, 2011). These impacts are discussed further below.

Rainfall

Across the whole of Southeast Asia, Werth & Avissar (2005a) predict that there would be reduced rainfall of 1mm/day throughout the year following deforestation. Olchev *et al.* (2008) enhance this idea, after models indicated that a 15% decrease in tropical rainforest in Sulawesi, Indonesia showed a 2% decrease in monthly evapotranspiration and a 21% increase in soil evaporation. Sen *et al.* (2004) predicted that deforestation in Myanmar could cast a rain shadow to the east, influencing rainfall in Bangladesh and northeast India. However, no additional studies on this rain shadow are, as yet, available.

Deforestation, which had previously been focused on lowland areas in Southeast Asia, is now moving to upland areas. Sen *et al.* (2010) model climatic changes that result from the replacement of montane forests with either irrigated crops or grassland: Southern China and Vietnam experience a 20–30% decline in rainfall, while the South China Sea sees a 30% increase in rainfall. Replacement with grass is shown to cause similar but enhanced changes, with rainfall being reduced by 30% across the entire Indochina peninsula and montane region. Major river headwaters are located in montane mainland Southeast Asia, so changes in rainfall would impact upland and lowland regions, as well as agricultural production.

Temperature

There are currently few modelling studies on temperature change due to deforestation within Asia. However, Schneck & Mosbrugger (2011) predict a regional increase in surface temperature of 1°C due to reduced evaporative cooling (Figure 3, overleaf). The authors also suggest that ocean surface temperatures will fall in some regions due to reduced trade winds and weakened upwelling of cold, deep water.

Monsoons

Modelling studies of the Indochina peninsula emphasise the deforestation impact on the East Asian Summer Monsoon (Sen *et al.*, 2004). Complete tree removal causes an increase in wind speed and air temperature, and a decrease in water vapour, which leads to weakening of the monsoon flow over east China. At the same time, the frequency of rainfall changes, with a higher rainfall frequency in areas with an increased annual quantity of rain, such as those downwind of deforestation. Further models by Sen *et al.* (2010) find that a change from forest cover to irrigated crops causes enhanced monsoonal flow over the upland montane region of mainland Southeast Asia, but a weaker flow over the South China Sea. It is reported that a significant decrease in summer monsoon rainfall has already occurred in the Indochina peninsula, due to extensive lowland deforestation (Kanae *et al.*, 2001).

Mangrove deforestation

As well as acting as a nursery ground for fish species and retaining sediment, mangrove forests act as a physical barrier against tidal and ocean influences such as tsunamis (Dahdouh-Guebas *et al.*, 2005; Sjöling *et al.*, 2005). Between 1990 and 2010 there was a loss of 0.5 million hectares of mangrove forest, with the current area standing at 15.6 million hectares (FAO, 2010).

Mangrove trees protect coastlines from tidal and ocean influences by reducing wave amplitude and energy (Danielsen *et al.* 2005). Despite this vital service, around 50% of the world's mangrove forests have been destroyed (Dahdouh-Guebas *et al.*, 2005). Communities that were located behind intact mangrove forests suffered less damage than those that were exposed during the "Boxing Day" tsunami of 26 December 2004 (Kathiresan & Rajendran, 2005). This highlights their importance and protective qualities for communities. Sjöling *et al.* (2005) report that deforested mangrove areas had higher sulphide and ammonia concentrations, low bacterial diversity and low nitrogen fixation rates. These changes are likely to modify the remaining habitat, making it unsuitable for seed propagation and mangrove forest re-establishment.

Teleconnections

Several authors have modelled teleconnections resulting from Asian deforestation. Werth & Avissar (2005a) indicate that, as the area of Asian deforestation increases, so does the impact to regions outside of Asia. For example, a 66% reduction in forested areas would extend the area of reduced rainfall and increase the number of months experiencing a significant decrease in rainfall. With total deforestation (100% reduction), this reduced rainfall area would extend from Southeast Asia into the Indian and western Pacific Oceans. Geopotential height changes also spread with increasing deforestation, impacting regional weather systems (Figure 4, overleaf).

"Tropical rainforests and peat swamps, the primary source of fire emissions in Southeast Asia, rarely burn without human instigation. If such deforestation fires were to be halted, fire activity in this region (and the associated mortality) would be minimal."

– Johnston *et al.*,
2012

Geopotential height is a scaled measure of the height of pressure surfaces in the atmosphere taken from mean sea level. Southeast Asian deforestation models indicate a 20-25% decrease in rainfall in western Turkey, as well as China (Avisar & Werth, 2005). Snyder (2010) suggests that European storm tracks may be changed due to large-scale atmospheric circulation changes caused by tropical deforestation. For example, models suggest enhanced storm track activity over Scandinavian countries impacting surface temperature via adiabatic warming (warming by compression without the gain or loss of heat).

Schneck & Mosbrugger (2011) also find global impacts due to Asian deforestation in their model. In high latitudes such as Siberia, the model indicates a decrease in temperature by up to 1°C, due to changes in atmospheric circulation, and increased snow and ice cover (Figure 3). It is thought that this area may be more sensitive to changes, as oceanic currents do not suppress feedback mechanisms. The authors also indicate increased temperatures in South America, Canada and central Africa. This model also includes the oceans, which are found to have a decrease in surface currents in the South China Sea and eastern Pacific Ocean, impacting upwelling of deep water. This could potentially impact nutrient availability and ocean temperatures.

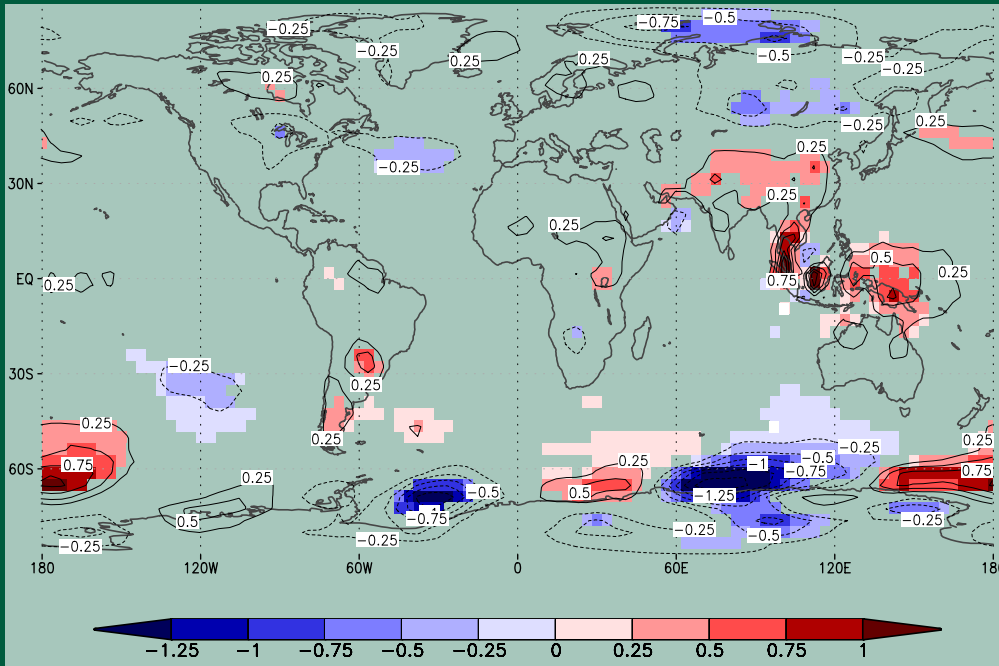


Figure 3: Model output of temperature change (°C) due to deforestation in Southeast Asia. Contour line intervals at 0.25°C (0°C is not shown). Significant ($p=0.05$) positive change is coloured red and significant negative change is coloured blue (Schneck & Mosbrugger, 2011). Output shows increases in temperature greater than 1°C in Southeast Asia and the South Pacific Ocean, and decreases greater than 1°C in the southern Indian Ocean and Siberia.

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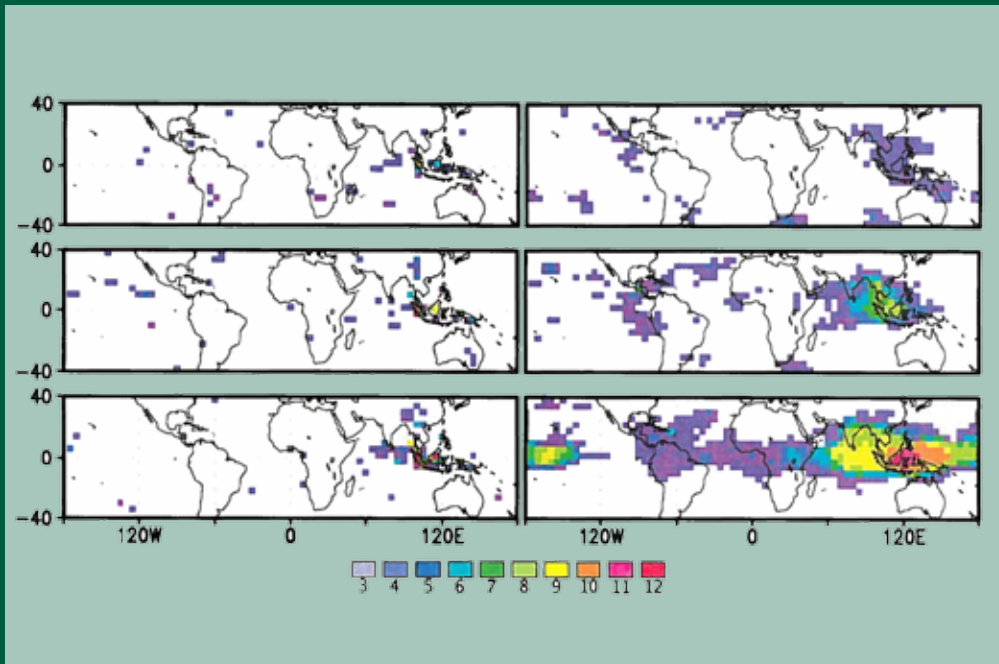


Figure 4: Model output of the number of months (coloured scale bar) where a significant ($p=0.05$) change of rainfall (left) and geopotential (247 mb) height fall (right) would occur after Southeast Asian deforestation. Top output is after 33% deforestation, middle output is after 66% deforestation, and bottom output is after 100% deforestation (Werth & Avissar, 2005a). Output shows increased deforestation results in significant rainfall and geopotential height fall changes.

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4. INDIRECT IMPACTS OF AFRICAN DEFORESTATION



Clearing of rainforest through fires, in the Democratic Republic of the Congo.
© Thomas Einberger / argum / Greenpeace

Africa contains 17% of the world's total forest area, mainly located in equatorial regions (FAO, 2010). These forests have the lowest average rainfall of all rainforests (Malhi & Wright, 2004), so may be strongly impacted by changes in rainfall. Deforestation in Africa is expected to result in warming of the land surface, reduced evaporation rate, increased surface albedo, reduced net radiation, reduced cloud cover, and reduced rainfall (Snyder *et al.*, 2004). These impacts are discussed further below.

Rainfall

The impact of complete African deforestation is modelled by Werth & Avissar (2005b). Results indicate that local climate would respond with a decrease in rainfall of up to 1mm/day, especially during the dry season in July. A strong decrease is found by Semazzi & Song (2001) when they model total deforestation over the whole of Africa with savannah grassland replacement. During the dry season from July to September, there is a 2-3mm/day decrease in rainfall, and a delay in the onset of the wet season. However, this decrease is not uniform over the whole continent; Mozambique would experience reduced rainfall, but Botswana, Zambia and the southern Democratic Republic of Congo would all experience an increase in rainfall.

Complete deforestation of the Congo basin is modelled to result in reduced precipitation of up to 50% (Nogherotto *et al.*, 2013). Deforestation in the Horn of Africa has been undertaken to enlarge agricultural areas, and several studies have investigated the climatic impacts of deforestation. Models by Otieno & Anyah (2012) suggest that the loss of forests in Kenya results in a decrease in monthly rainfall, and could lead to a shift in moisture convergence zones. Salih *et al.* (2012), model deforestation in Sudan and South Sudan, with forest being replaced by grass or desert. The results indicate a decrease in rainfall during the wet season (July to September) by 0.1-2.1mm/day for desert, and 0.1-0.9mm/day for grass.

Temperature

Snyder *et al.* (2004) suggest that land surface temperatures would increase due to deforestation in Africa. This is supported by modelling studies that find increases of 1.2°C (desert) and 2.4°C (grass), depending on the type of habitat following deforestation (Salih *et al.*, 2012). Nogherotto *et al.* (2013) find significant warming of up to 4°C following deforestation of the Congo basin.

Monsoon

Modelling indicates that the removal of trees decreases rainfall in West Africa, as the mid-troposphere retains more monsoon moisture. This results in reduced northward transport of moisture, which produces rainfall over West Africa. An increased easterly mid-troposphere flow speed also contributes towards decreased rainfall, as it transports moisture away from West Africa (Abiodun *et al.*, 2008). Nogherotto *et al.* (2013) also find changes to the West African monsoon in deforestation models, with intensification over the Guinean coast but a decrease in precipitation in the Sahel. The south equatorial monsoon is found to strengthen with increased precipitation over southern equatorial Africa.

Agriculture

Individual country models exist for the impacts of deforestation on agriculture, but regional scale models are absent. A study by Giertz *et al.* (2005) reports that deforestation in central Benin increases the water yield of soil due to increased surface run-off and evapotranspiration. Otieno & Anyah (2012) suggest that decreased rainfall due to the loss of forests in Kenya could impact agricultural production in western Kenya. Reduced rainfall, especially in the dry season, combined with increased evapotranspiration, would reduce the soil water content and increase water stress. Increased surface run-off could remove soil and nutrients from cropland, also impacting agricultural production. These conditions may exacerbate the reduced agricultural output and the lack of food security currently present in some African countries, particularly those in the Sahel and Horn of Africa.

Teleconnections

Modelling studies suggest evidence of global impacts association with deforestation in Africa. Avissar & Werth (2005) use models to show that removal of forests in Central Africa would cause a 5-15% decrease in rainfall in the Great Lakes region of the midwest US, with a peak decrease of 35% in February. Models by Werth & Avissar (2005b) indicate a geopotential fall in September throughout the tropics, centred over Africa. There is a rainfall decrease over the tropical Atlantic and Gulf of Mexico. This could be linked to distinct atmospheric highs over Alaska and lows over North America leading to impacts on rainfall (Werth & Avissar, 2005b). The US accounts for 40% of global maize and soybean production (Lobell *et al.*, 2011). The midwest region is a key agricultural area, and decreases in rainfall are likely to affect crop output and global food supplies. Conversely, according to models by Avissar & Werth (2005), deforestation of central Africa increases rainfall in the Arabian Peninsula by 15-30% during August and September.

5. INDIRECT IMPACTS OF AMAZON DEFORESTATION



An illegally logged area near Santarem. Illegal logging is still driving destruction in the Amazon.

© Karla Gachet / Panos / Greenpeace

The Amazon region in South America contains 21% of the global forest area (FAO, 2010). Due to its size, regional differences in impacts are expected to occur, and have been previously indicated by modelling studies. Models suggest that the Amazon region will have reduced rainfall, changes to regional temperatures and an increased flood risk with deforestation. These impacts are further discussed below.

Rainfall

Deforestation within the Amazon is expected to reduce rainfall, and Moore *et al.* (2007) suggest that total deforestation of the Amazon would result in a 10- 20% decrease in annual rainfall across the entire Amazon basin. This is expanded by Spracklen *et al.* (2012), who model a rainfall decrease across the Amazon basin by 2050 of 12% during the wet season and 21% during the dry season. Even areas outside of deforested regions would be impacted, with the southern Rio de la Plata Basin predicted to have a 4% decrease in rainfall (Figure 5). Coe *et al.* (2013) report that savannah deforestation in southern central Brazil may already be reducing rainfall in south-southeastern Amazonia, hundreds of kilometres downwind.

It is expected that deforestation will have regional differences in impacts across South America. This is highlighted in modelling studies by Medvigy *et al.* (2011), who suggest that the northwest Amazon will become drier by up to 2mm/day, while the southeast Amazon will become wetter by up to 1.5mm/day. This is caused by changes in moisture convergence, with an average decrease in rainfall of 2.3%. However, deforestation in the Atlantic Forest on the east coast of Brazil does not exhibit a strong relationship between forest cover and total rainfall (Webb *et al.*, 2005)

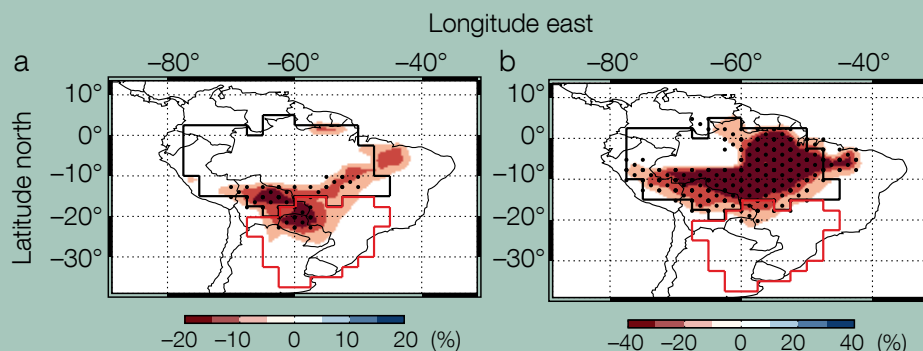


Figure 5: Model output of percentage rainfall change (colour scale) due to deforestation of the Amazon basin during the wet season (a) and dry season (b). The black-outlined area indicates the Amazon basin and the red-outlined area indicates the Rio de la Plata basin. Black dots highlight rainfall anomalies that differ by more than one standard deviation (Spracklen *et al.*, 2012). Output shows a marked decrease in rainfall in the Amazon and neighbouring basins.

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Flood risk

The hydrological impact of Amazon deforestation is modelled by D'Almeida *et al.* (2006). The authors find that water fluxes decline with all sizes of deforested area, but there are noticeable differences too. For example, with limited deforestation (less than 102km²) there are local increases in run-off, but with extensive deforestation (more than 105km²) the water cycle is shown to weaken.

In the southeastern Amazon, the impact of deforestation on the hydrological cycle has been separated from natural climatic changes. In the Tocantins River, the area of crop and pasture land increased from around 30% to 50% between 1955 and 1995. This led to increases in annual river discharge by 25%, but there were no significant changes in rainfall (Costa *et al.*, 2003). In the Araguaia River, deforestation has occurred since the 1970s, with the average annual discharge shown to have increased by 25% between the 1970s and 1990s. The sediment load of the river was found to have increased by 28% (Coe *et al.*, 2011). Davidson *et al.* (2012) pointed out that discharge increases the most during the wet season, in turn increasing the risk of flooding in these regions.

Temperature

Surface temperatures are expected to increase following tree clearance, but increased frequencies of cold events are also expected. Feddema *et al.* (2005) report that the complete conversion of the Amazon rainforest to agriculture would result in a temperature increase of over 2°C.

Medvigy *et al.* (2011) suggest that models indicate that the frequency of extreme cold events (a decrease in temperature of more than 1°C) would increase. Further studies by Medvigy *et al.* (2012) investigate these extreme cold events. Deforestation models predict that these events could triple in frequency in the west and south of South America but decrease in frequency in the east. They note that the southern La Plata Basin is particularly vulnerable to changes in climate. It is suggested that the increased frequency of extreme cold events is caused by positional changes of the subtropical jet stream due to temperature changes in the Amazon basin.

Stream temperatures in the Xingu Basin in Mato Grosso, Brazil are shown to be significantly warmer in watersheds with pasture and soya bean than those in forested watersheds (Macedo *et al.*, 2013). Average daily maximum stream temperatures are over 4°C higher in pasture and 3°C in soybean watersheds than forested ones. The authors suggest that this is due to agricultural expansion, and may negatively impact fish and other species in the streams.

Agriculture

Decreased rainfall and increased frequency of cold events is likely to impact the Amazonian agriculture industry, which is worth \$15bn US dollars a year (Aragão, 2012). Changes to rainfall patterns modelled by Spracklen *et al.* (2012) are suggested to negatively impact crops and soil conditions. Medvigy *et al.* (2012) suggest that the La Plata Basin in southern South America, a major agricultural area growing soybean, wheat, maize and rice, could be negatively impacted by changes in temperature caused by deforestation. Crop damage due to cold events has already been recorded for coffee in southern Brazil, and wheat, soybean and citrus harvests in Argentina and southern Brazil (Medvigy *et al.*, 2012).

Teleconnections

There are limited studies on teleconnections resulting from Amazon deforestation. Avissar & Werth (2005) report that forest clearance could result in changes to rainfall patterns in the Gulf of Mexico, with severe decreases (25%) in Texas during spring and summer. However, increases in rainfall by up to 45% are predicted in August and September in the Arabian Peninsula and counties surrounding the Red Sea. Northern Europe is also shown to experience enhanced rainfall throughout the year, but this would be less significant than the increase in the Arabian Peninsula. Models suggest that temperature increases could lead to a weakening of the Hadley circulation, impacting worldwide atmospheric circulation and the Asian monsoon (Feddema *et al.*, 2005).

6. INDIRECT IMPACTS OF BOREAL DEFORESTATION



Remains of an old growth forest situated on the edge of a lake in Peurakaira, Finland. Deforestation caused by a state-owned logging company and others threatens the natural habitat of the reindeer herds and the traditional livelihood of the local Sámi people.
© Greenpeace / Tim Georgeson

There is little information on the indirect impacts of deforestation of boreal forests. Models indicate that deforestation could cause regional cooling in the northern hemisphere winter and spring, causing snow melt to occur later and leading to cooler temperatures (Strengers *et al.*, 2010). Clearance of the boreal forests in northern Europe, Asia and North America could increase surface albedo by up to 25% (Bala *et al.*, 2007), enhancing albedo-induced cooling. Lee *et al.* (2011) report that observational air surface temperatures are lower in open land than boreal forested areas in Canada and the US. The authors suggest that this is an example of the albedo cooling effect.

7. SYNTHESIS AND CONCLUSIONS



Single tree in a soy field next to rainforest, south of Santarem and along the road BR163. Cutting through the Brazilian Amazon from north to south over a vast distance of 1,700 km this highway has been one of the major drivers of deforestation in the region for the past 20 years.
© Daniel Beltrá / Greenpeace

Changes in land cover, including deforestation, can lead to reduced evapotranspiration and enhanced surface temperatures. This alters atmospheric moisture and circulation patterns, resulting in local and regional climatic changes that are propagated around the world to distant regions by teleconnections. Modelling these changes allows the indirect impact of deforestation to be investigated, both regionally and globally.

Deforestation can lead to human health issues caused by the release of smoke during clearance burning. Worldwide, an average of 339,000 deaths a year are estimated to be attributable to exposure to landscape fires, which predominantly arise from fires set in tropical forests and savannah in Southeast Asia and Sub-Saharan Africa. In Southeast Asia, fire emissions are estimated to contribute towards an additional 200 days a year on which World Health Organisation air quality targets are exceeded. There are also concerns that forest clearance may increase the spread of diseases such as malaria, due to increased temperatures, artificial water ponds, and the loss of forest pathogen hosts.

The hydrological cycle is disrupted and weakened by deforestation due to the decrease in evapotranspiration and moisture circulation, with models suggesting that annual rainfall could be reduced by up to 80%. This impacts the agriculture industry and water availability, while the loss of trees also contributes towards increased run-off and flood risk. Models suggest that flood frequency is positively correlated with the amount of forest area lost; indicating that flooding will increase with future deforestation.

Temperate and boreal zones in the northern hemisphere are expected to undergo a regional cooling effect due to global deforestation, while tropical regions would undergo regional warming. Models indicate that forest loss in the three main forest regions (Asia, Amazon and Central Africa) could cause a 2-3°C temperature increase, strongly impacting agriculture.

Asia is thought to have the most complex deforestation impacts due to its island geography, the effect of the Asian monsoon, and strong ocean-atmosphere feedbacks. Models suggest there would be a reduced annual rainfall of 1 mm/day and increased surface temperatures of up to 1°C following tropical forest clearance. These changes are expected to weaken the Asian monsoon over the South China Sea, but strengthen it over upland mainland Southeast Asia. Deforestation of mangrove forests for aquaculture may leave communities more vulnerable to damage from cyclones and tsunamis, as mangrove barriers would no longer reduce wave energy.

African forests have the lowest average rainfall out of all forests, so are expected to be highly impacted by changes in rainfall due to deforestation. Models indicate that a decrease in rainfall of up to 1 mm/day would be caused by forest clearance, which would be amplified in the dry season and could delay the start of the wet season. There was regional variation across the continent, with reduced rainfall in the southeast and Horn of Africa but increased rainfall in central Africa. It was suggested that the monsoon would also be impacted, with a reduction in moisture transport over West Africa. Land surface temperatures are modelled to increase between 1.2 and 2.4°C, depending on the vegetation type replacing the rainforest. Studies also predicted a decrease in agricultural production due to reduced rainfall and increased soil water stress, threatening food security in Africa.

As the Amazon is the largest forest area in the world, it is expected to have more pronounced regional variations and a greater impact on remote regions. Models demonstrate that deforestation could cause a 10-20% decrease in rainfall across the Amazon basin, with regional changes also noted outside of deforested areas. The northwest Amazon is suggested to have a decrease in rainfall of up to 2 mm/day, while the southeast is suggested to have an increase of up to 1.5 mm/day. There is evidence that deforestation in South America has led to increased flood risk and increased annual river discharge by 25%, which may be exacerbated by further deforestation. Surface temperatures are predicted to increase by 2°C, and the frequency of extreme cold events could possibly triple. The change in rainfall and cold events are suggested to negatively impact crops and soil conditions, affecting agricultural production of coffee, soybean, maize and wheat.

There is limited information on the indirect impacts of boreal forest loss, but it is predicted to result in regional cooling. This is due to albedo-associated cooling effects and delayed spring snowmelt.

Modelling studies suggest that impacts propagate around the world due to teleconnections, impacting rainfall patterns and storm tracks far away from deforestation areas. Modelling suggests that Asian deforestation could result in a rainfall decrease of up to 25% in Turkey, alteration and intensification of European storm tracks and reductions to surface ocean current speeds in the South China Sea and eastern Pacific Ocean. African forest loss is suggested to reduce rainfall in the midwest US by 5-35%, negatively impacting a major agricultural region and increasing water stress. However it is reported that some regions, such as the Arabian Peninsula, would have increased rainfall of up to 30% due to changes in rainfall patterns caused by central African deforestation.

Modelling studies suggest that impacts propagate around the world due to teleconnections, impacting rainfall patterns and storm tracks far away from deforestation areas.

A decrease in Amazon forest cover indicates a 25% decrease in rainfall in Texas during spring and summer, but an increase in rainfall of up to 45% for the Arabian Peninsula due to changes in moisture circulation. Northern Europe is also suggested to have increased annual rainfall, although not to the same extent as the Arabian Peninsula. These models indicate that the Amazon region has the strongest impact on hydroclimatic changes in remote regions, possibly due to its large forest area, but other regions of deforestation also have significant impacts.

Many authors agree that there is evidence of deforestation causing change to local and regional temperatures and rainfall. However, these impacts do alter between forest regions. For example, while both Asian and African deforestation changes regional rainfall patterns, the effect of deforestation is strongest during the dry season in Africa, but distributed throughout the year in Asia. There is also some evidence for significant remote impacts caused by deforestation teleconnections. As this is an emerging field, it is expected that further studies will be needed to investigate the links between deforestation-induced climatic changes and agriculture, as well as remote impacts. Despite most studies using models of complete deforestation, the impacts can indicate changes that may occur even with current rates of forest cover loss.

Although studies may agree on the impacts, there is disagreement on the magnitude, extent, location and physical causes that generate them. There are also no studies that investigate the cumulative effects of indirect impacts. For example, Amazon forest clearance may impact the Asian monsoon, which is also impacted by deforestation within Asia. It is not yet known if these impacts may amplify each other or cause other as yet unknown impacts.

Ending deforestation would stop the direct loss of forest habitat but it would also minimise the indirect effects of deforestation, and the possibility of changes to weather and climate systems locally, regionally and globally. There would also be benefits to public health, reductions in flood risks, and decreases on the negative impacts on crop output in certain areas. Our knowledge of the ecosystem services provided to humans by forest ecosystems (underpinned by biodiversity) is incomplete, and hence the full consequences of their loss cannot be known, or even estimated with any certainty. Therefore, employing the precautionary principle and conserving existing forest ecosystems under a “Zero Deforestation” footprint is the only way to ensure that forests continue to regulate our weather and climate, minimise the indirect effects of deforestation, and conserve biodiversity.

“These models indicate that the Amazon region has the strongest impact on hydroclimatic changes in remote regions, possibly due to its large forest area, but other regions of deforestation also have significant impacts.”

– (Aragão, 2012)



The expansion of the soya industry is one of the main causes of deforestation in the Amazon rainforest, as huge areas are cleared to meet agricultural demand. Trees stand on the edge of a manmade field that has been cut through the natural forest.
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