Chapter 12

Tropical forests and large rivers

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Banks of the Rio Negro in the Norte region of Amazonia (Brazil).

Humid tropical forests form nearly a third of the forest areas in the world. More than other environments, they have become indissociable from the climate question. Indeed, their role in carbon dioxide sequestration is at the centre of climate policies while deforestation in recent decades has been recognised as being responsible for a fifth of greenhouse gas emissions.

Like these forests, the large rivers that flow through them are emblematic of the humid tropical climate. The large Amazon and Congo River basins—the largest in the world—are directly affected by climate phenomena like El Niño, monsoons, droughts and tropical cyclones. More numerous and more severe floods and low-water periods have been observed in recent years. These events disturb ecosystems and the neighbouring populations and also water supplies for towns.

A climate regulator in danger

Humid tropical forests play an important role in climate regulation. They absorb solar radiation, cool by evapotranspiration and are sources of water vapour for the creation of clouds. Amazonia and the role it plays in rainfall in the South American subcontinent

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Karnataka (India).
The large tropical forests that play an important role in carbon sequestration form nearly a third of world forest area.

is a much-observed example. According to estimates by scientists, approximately half of the rainfall in the Amazon basin is derived from forest evapotranspiration. Amazonia releases about 20 billion tonnes of water into the atmosphere every day.

Carbon sink

Tropical forests also play an indirect role in the world climate machine by way of the carbon cycle. They store a quarter of the organic carbon of the biosphere. The carbon sink mechanism linked with the positive difference between the carbon used in photosynthesis and that emitted by respiration enables them to capture part of the CO_2 present in the atmosphere (Box 36). Tropical forests can therefore be considered as natural infrastructure for combating the greenhouse effect.

However, climate change may change the functioning of this 'green lung'. We already know that climate warming will disturb the carbon cycle. It is considered in some studies that an increase of a few tenths of a degree could cancel out the present biosphere carbon sink because of an increase in soil respiration. But the sensitivity of organic carbon stocks and respiration to warming is still the subject of intense debate. Scientists are therefore working on gaining better understanding of the impacts of climate change on forest biomass and on the carbon sink function.

Box 36

Carbon sequestration in biomass and soil

The difference between the quantity of carbon assimilated by photosynthesis in land vegetation and that emitted by respiration is slightly positive. Vegetation captures some 120 Gt of carbon from the atmosphere by photosynthesis each year, that is to say about 1 atmospheric carbon atom in 7.
At the same time, plants respire and emit CO_2, returning about half of what they consume to the atmosphere. The other half returns to the atmosphere very broadly via soil respiration (roots, microorganisms and fauna).
As the amount of carbon taken up by photosynthesis is slightly greater than that released by plant and soil respiration, part of the atmospheric carbon taken up by plants is stored in biomass and soil in the form of organic matter: this is carbon sequestration.
This process makes land ecosystems a sink that slows the increase in atmospheric CO_2.

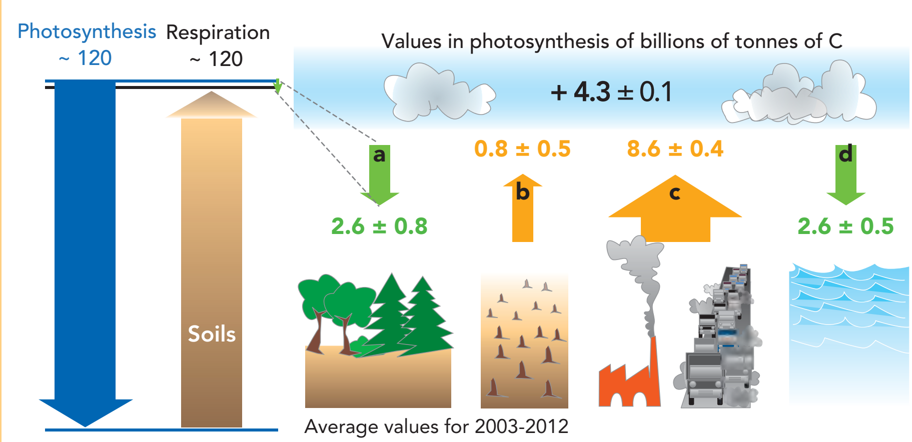

Figure 25.
Carbon exchanges between ecosystems and atmosphere.
a/ Carbon sequestration in soils resulting from gas exchange between photosynthesis and the respiration of plants and soil organisms and microorganisms.
b/ Soil to atmosphere carbon flow following deforestation.
c/ Non-agricultural or forestry anthropic emissions of CO_2.
d/ Ocean CO_2 sink.
Sources: BERNOUX and CHEVALLIER, 2013 and www.globalcarbonproject.org

Deforestation

There is a scientific consensus on the impacts of deforestation on the climate. According to the IPCC Fifth Assessment Report, since the 1980s the deforestation of several million hectares of tropical forest in Amazonia and insular Asia forms the greater part of greenhouse gas emissions resulting from change in land use. In addition to releasing the carbon stored in trees and forest soils, the disappearance of forests also halts their carbon sink function. The sustainable storage potential of the land use replacing forest is generally very small. In addition, degraded forests store less carbon.

With the increase in temperature and droughts, fires in degraded forests can have serious consequences for forests and hence the climate. The southern and eastern edges of Amazon have suffered serious deforestation and the spread of fires has made the natural forest even more fragile.

In spite of a relatively recent slowing, deforestation still has a future. It is the driving force of the economic model of emerging countries, such as Brazil and Indonesia, which rely increasingly on the export of primary raw materials to fund their policies. Forest areas form a land reserve for the spread of crops (soy, maize, oil palm and sugar cane) and cattle farming. Pressure on these areas will increase with world demand for these goods. Land holding security policies are necessary in such a context but are often weak. But the fight against deforestation is bearing fruit in some countries such as Brazil thanks to national nature protection policies (50% of Brazilian Amazonia is listed as protected areas) and surveillance by remote sensing. Carbon market mechanisms will also play a role in fighting deforestation although they are slow to gain power and their effectiveness is called into question by part of the scientific community (see Part 3, p. 180).

Bukit Barisan Selatan National Park in Sumatra (Indonesia). The park has lost about 20% of its area as a result of deforestation, mainly for coffee planting.

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Measurements of biomass.

Evaluating carbon sequestration in tropical forests

Given the international objectives of mastery of greenhouse gas emissions, a mechanism to encourage the conservation of carbon stocks in tropical forests was set up in 2009. REDD+ (Reduce Emissions from Deforestation and forest Degradation) is aimed at preventing deforestation and the degradation of forests in tropical countries. The measurement of forest carbon, the links between deforestation that has been avoided and its effect on the carbon stocks together with the monitoring of emission reduction undertakings form a scientific and methodological challenge, especially as regards the quantification of forest degradation other than deforestation. Research institutions have thus been called upon to provide methods and synthesise carbon stock census data for these forests.

Carbon stocks consist mainly of the above-ground biomass of the trees (trunks and branches) and also forest floor plant debris, soil organic matter and tree roots. Field estimation of tree biomass is based on simple measurements that can be made during forest inventories, such as trunk diameters. 3D imagery can also be used. But given the constraints of forest areas that are vast and to which access is often difficult, the spatial coverage of forest inventories is limited in terms of area. Biomass censuses are very expensive and not regular enough for good measurement of the evolution of stocks. These *in situ* measurements must therefore be combined with aerial and satellite remote sensing techniques. Field records are then used to sample the different types of forest in an area and to calibrate tree biomass and population prediction using remote sensing data.

Numerous remote sensing facilities

Estimating forest biomass using remote sensing is a strongly developing field of research. Unlike deforestation monitoring, a comparatively well-mastered technique, that of forest degradation and more generally of variations of forest biomass in space and time is difficult as most signals saturate at intermediate biomass levels. In recent years the diversification of sensors and of data sources have improved biomass measurements. Canopy heights are measured by laser altimetry (Lidar) allowing effective measurement of standing biomass. However, it is still dependent on airborne support that is costly and subject to over-flying authorisations. The European Space Agency’s future radar satellite designed for biomass estimation should give results in a few years.

Box 37

How much carbon is stored in deforested soils in Amazonia?

Together with oceans and forest, soils form one of the main carbon reservoirs of the planet. This stock decreased considerably in the 20th century as a result of deforestation and intensive farming. IRD researchers and their Brazilian partners have been particularly interested in the evolution of the quantities of carbon in the soil following deforestation in Amazonia. Land that is stripped and then cultivated releases into the atmosphere as CO_2 the carbon hitherto stored as organic matter.

The response of soil after deforestation is very heterogeneous. To understand it better, researchers analysed a large amount of data on the evolution of soil carbon stocks in the region. They examined the results of about 20 studies conducted since 1976 on cattle grazing or fields of soy or maize that replaced forest. They then compared the quantities of organic carbon measured in these deforested soils with those of the initial forest.

Soil carbon decreases with crops but not with grazing

Unsurprisingly, the Franco-Brazilian research team showed that the replacement of forest by large-scale annual crops such as maize and soy causes an average decrease of 8.5% in soil carbon. This feature is explained by the small quantities of organic matter returned to soil with no forest cover and also by cultural practices that favour carbon loss.

In contrast, the quantity of inorganic carbon in the soil has increased slightly in grazing land since forest clearance. The figure is an average of 11% in prairie that is not over-exploited. The vigorous root activity of grasses improves soil carbon storage. However, researchers expected much higher figures in grazing land as this is assumed to have a greater carbon sequestration potential. In addition, the increase in the amounts of carbon from grasses reaches a threshold after about 20 years and therefore in no way compensates the global greenhouse gas emissions resulting from deforestation.

Finally, the synthesis shows that in contrast with what is observed elsewhere in the world, the quantity of precipitation has no effect on soil carbon storage capacity in Amazonia.

Pastures replacing Amazonian forest in Brazil.
Intense deforestation for agricultural purposes contributes to reducing the carbon reserves stored in tropical forests.

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GeoEye 'false colour' very high spatial resolution image of the canopy.
The grain texture of satellite images of canopies is a good indicator of forest biomass.

© IRD/Amap

Finally, the increasing availability of very high spatial resolution (pixels of 1 m or less) optical satellite images also provides ways of predicting forest biomass. IRD and its partners have developed a method (Foto) in which the grain texture of satellite images reflects the size of crowns and hence that of the dominant trees that often form nearly three-quarters of the biomass of a forest. The approach has been validated in case studies involving very varied forests in Central Africa, French Guiana, India and New Caledonia. Other research has shown how to apply these methods to heterogeneous images in terms of illumination and the angle of aiming of the sensor. The research carried out in the last decade makes it possible today to envisage the combining of different complementary remote sensing techniques with each other and with field inventories.

Climate has had effects on humid tropical forests for thousands of years

According to the IPCC Fifth Assessment Report, tropical forests might be more sensitive to climate variations than temperate forests as they have evolved within a smaller temperature range than forests at high latitudes. It is necessary to examine the past to gain better understanding of the role of climate in forest dynamics. For some 20 years, several international multidisciplinary teams have worked in the Amazon and Congo basins on studying the evolutions of tropical forest in the last few thousand years and the role played by climate.

Box 38

The carbon balance of the Amazon is probably neutral

The carbon balance of the river system in central Amazonia is close to neutral: water releases the same quantity of carbon into the atmosphere as that fixed by the vegetation in its wetlands.

Considered up to now as a source of greenhouse gas emission, the river Amazon in fact shows carbon neutrality. A 2013 study by the GET and Epoc laboratories, within the framework of the HYBAM watch, shows that the CO_2 released by the river is only drawn from the river system itself.

Until now, scientists thought that the rivers received carbon from trees and other terrestrial plants via the soils of the drainage basin. The carbon would then be turned into CO_2 and released into the atmosphere. The watercourses, and particularly the gigantic river Amazon, were therefore considered to be net sources of emissions, with CO_2 released exceeding uptake. But researchers have demonstrated recently that the 200,000 tonnes of carbon released as gas annually by the waters of the Amazon is drawn mainly from the respiration and decomposition of the organic matter produced by semi-aquatic vegetation in the Amazonian wetlands. In contrast with what was thought previously, the river thus operates as a 'CO_2 pump'.

The study also highlights the need to examine the specific properties of wetlands in global carbon balances.

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The River Amazon emits 200,000 t of carbon annually.

© IRD/R. Oslisly

Mosaic of forest and savannah, Lopé National Park, Gabon.

Research on the last 5,000 years in central Africa contradicts the vision of unchanging humid tropical forest. Forests became fragmented 2,000 to 2,500 years ago to the advantage of savannah. The regression of forests seems to have been linked with the weakening of the African monsoon 3,500 years ago. After this period of drought, forest gradually regained land. Pollen analysis revealed the renewed presence of herbaceous and other plants characteristic of degraded forest or savannah during the Small Ice Age (14th to 19th centuries). Archaeological studies show that technical and cultural evolutions ran in parallel with these regional environmental changes. The influence of humans does not seem to have been determinant in changes in the environment even though it very probably enhanced certain dynamics, especially through fires. The work shows that African forest—generally drier than Amazonia—swings more rapidly to savannah landscapes as a result of fires in particular. But the continued existence of refuge zones for forest species in certain mountain areas or near rivers makes reconquest periods possible, as was the case in recent centuries.

Climate is also one of the driving forces of biodiversity. Species diversity in Amazonia is among the greatest of all terrestrial areas and results from evolution in an environment where there have not been any mass extinctions of species caused by glacial intrusions in northern latitudes and that has been comparatively well protected from the accompanying spread of dry tropical climates. However, recent work by an IRD team and its South

American partners shows that the exceptional fauna and flora of the Amazon basin are also the result of a long geological and climate history. Active tectonics in the Andes and the variability of precipitation appear to be what drive the development of biodiversity hot spots in the foothills of the Andes. Changes in the relief (tectonics, erosion, changes of courses of rivers) would set up an unstable regime favouring considerable species diversification.

The hydrology of large rivers: more severe flooding and low water periods

The increase in extreme events (droughts, very heavy rain) observed in the tropics has resulted in more frequent and more intense floods and low water periods in the large tropical rivers. Much research has been carried out on Amazonia, the largest drainage basin in the world with an area of some 6 million square kilometres. Since 2003, the HYBAM environmental observation service has made precise, regular records of water flows and levels using a vast network of hydrological stations and satellite spatial altimetry (Box 39).

Water level surface elevation of rivers in Amazonia can vary by 20 metres

Over the past 15 years, there has been a succession of periods of exceptional low water (2005 and 2010) and of floods (1999, 2009, 2012 and 2014). While the average discharge of the river varies little, these events form the main marker of the change in hydrological regimes observed in the Amazon and its tributaries. Floods and extreme low water are related to the influence of oceans and possibly amplified by local factors. For example, deforestation reduces the moisture available during droughts and increases runoff during rainy periods.

These extreme events have had major local impacts. The surface elevation of the rivers in central Amazonia can thus vary by more than 20 m between low and high water periods and the Amazon can be as much as 10 km wide during the most severe floods. Floods and low water disturb communication in Brazil along waterways that are the sole lines of communication for a large proportion of the population of Amazonia. During these phenomena, the people who live along the rivers do not have their usual resources—fishing and farming in particular. Floods can also kill. In Bolivia in 2014, the catastrophic flood of the river Madeira, one of the main tributaries of the Amazon, caused 56 deaths and affected 58,000 families.

Box 39

Monitoring the exceptional Amazon basin flood of 2014

HYBAM teams used spatial altimetry and field measurements to monitor the start and evolution of an exceptional flood in the river Madeira from Peru to Brazil. The spatial hydrology facilities developed by IRD were made available to South American national technical divisions.

Shared between Peru, Bolivia and Brazil, the area of the river Madeira drainage basin is twice that of France. An exceptional flood occurred in 2014, caused by heavy rainfall in the basin from the beginning of the year onwards.
The level reached by the river at Porto Velho in Brazil was 2 metres higher than the previous maximum observed since measurements started in 1967.
At Rurrenabaque in the Bolivian Andes foothills, cumulated rainfall of 1,100 mm in 17 days was four times the usual figure for the period.
The Bolivian government considered the floods to be the most catastrophic for 30 years.

Cooperation with national agencies and universities in the three countries

HYBAM teams used the network of gauging stations of the Peruvian and Bolivian national meteorology and hydrology services and support from the Brazilian water agency to monitor the start and the progress of this exceptional flood.
Discharges of the river Madeira and its tributaries were measured at field stations. River water levels were also monitored using spatial altimetry. As the floods had washed away numerous gauging stations in Bolivia, water levels in this extreme context were monitored using the satellite data method.

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Damage caused by a flood of the Rio Madeira, Brazil, in 2014.

Box 40

Groundwater mapped from space

Researchers at the LEGOS, Espace-DEV and GET units and their French and Brazilian partners have developed a new method for satellite measurement of groundwater.
They have plotted the first maps of the groundwater beneath the Amazon and the Rio Negro.

They indicate aquifer depth during low water periods from 2003 to 2008 and show groundwater response, particularly to droughts such as that of 2005, thus giving a better description of its role with regard to the Amazon climate and ecosystem.

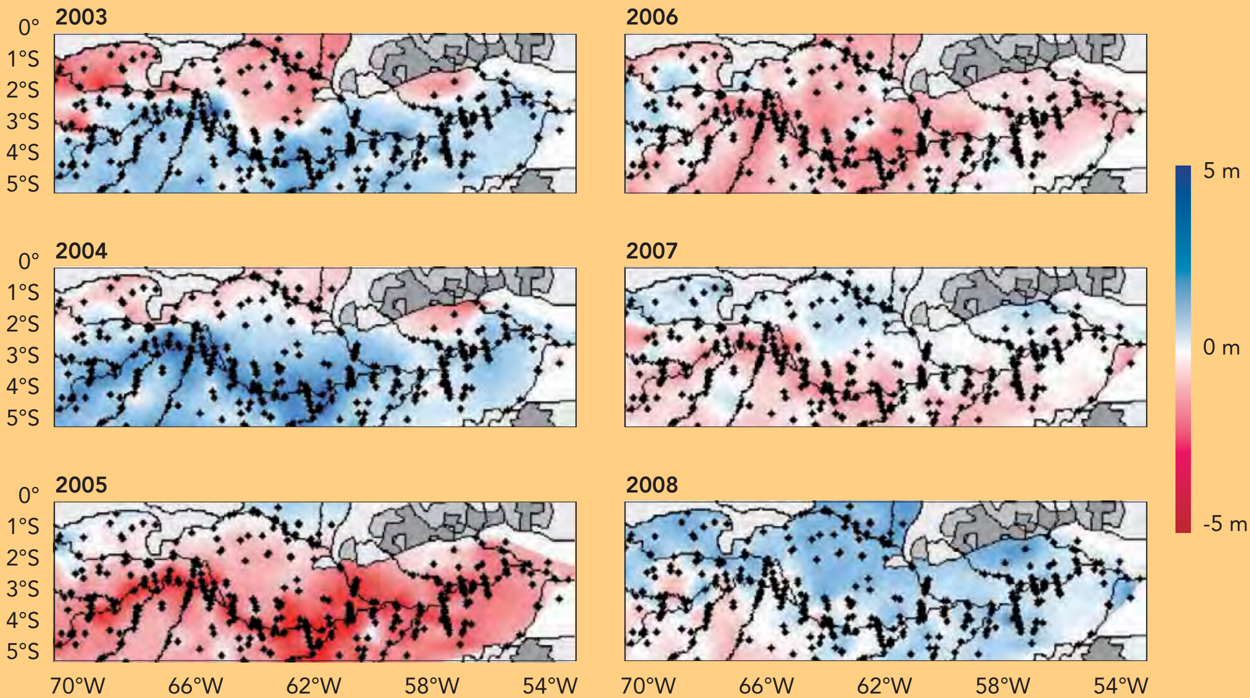

Figure 26.
Monitoring of the situation of Amazonian alluvial groundwater from 2003 to 2008.
Black diamonds = virtual altimetric stations.
Range of colour = height of the groundwater level in comparison with an average situation.
Groundwater did not return to its average level for two years after the severe drought of 2005 even though rainfall returned to normal in 2006.
Source: PFEFFER *et al.*, 2014.

Box 41

The lesser impact of climate change on the extinction of freshwater fish

In 2013, scientists at the BOREA research unit and their partners showed that current cases of extinction of freshwater fish as a result of anthropic pressure is probably much greater than those caused by climate change.

The models used to date by ichthyologists forecast that the reduction of the habitats of certain species caused by climate change would be one of the major causes of their extinction. However, these models did not allow for the time factor whereas it may take several decades or even several thousand years for a species to become extinct.

The BOREA researchers integrated the time dimension in their work and showed that the effects of climate change will only marginally affect the natural rate of extinction of freshwater fishes, except in semi-arid and Mediterranean regions.

The extinction rates caused by human activities in the last two centuries are much more disturbing as they are an average of 150 times greater than natural rates of extinction and 130 times greater than the extinction rates predicted in the light of climate change.

However, stress linked with temperature and limited oxygen could cause gradual changes in the structure and composition of present fish communities. In Amazonia for example, populations of species tolerant to a rise in temperature, such as *Arapaima*, will increase while those of populations sensitive to this will dwindle.

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Nannostomus trifasciatus Steindachner, 1876. Bolivian aquatic environments from the Andes to the Amazonian plains house 900 fish species, representing 6% of the freshwater fish that have been described.

These major rivers are also an important source of energy in the regions that they cross. Amazonia is still seen as an excellent area for the continued construction of large hydroelectric dams (Tucurui, Belo Monte, Santo Antônio, Girau) to supply large regional industries and towns. But the capacity of these installations might have been overestimated in the light of the strong climate fluctuations seen today (droughts and floods).

Seriously disturbed river traffic on the Oubangui

The Congo River, the second largest in the world after the Amazon, has also displayed considerable instability in discharge. This decreased significantly by about 10% in the early 1980s and then returned to normal from 1990 onwards. However, the discharges of the right bank tributaries—the Oubangui and the Sangha—have decreased steadily since the 1970s. But the Congo and the Oubangui are the main routes of access for trade between Kinshasa/Brazzaville and Bangui in the Central African Republic. The number of days of stoppage of river traffic on the Oubangui has increased considerably in recent decades and has been as much as 200 days per year since 2002. However, the very complex hydrology of this river basin with an area of nearly 4 million square kilometres makes it difficult to isolate major trends directly linked with climate change, especially as there are few hydroclimatic data for the region. Developed by IRD, BVET, a system for the observation of experimental tropical drainage basins, contributes to improving knowledge of hydrology in central Africa. With Cameroonian partners, BVET is studying the impact of climate fluctuations and agricultural practices on the hydrosystems of several small drainage basins in southern Cameroon. Another facility for monitoring the humid zone in central Africa is being set up in Gabon.

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River traffic
on the Congo River.
The Congo River is an important waterway for trade and passenger traffic between the two capitals, Kinshasa (Democratic Republic of the Congo) and Brazzaville (Republic of the Congo).

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