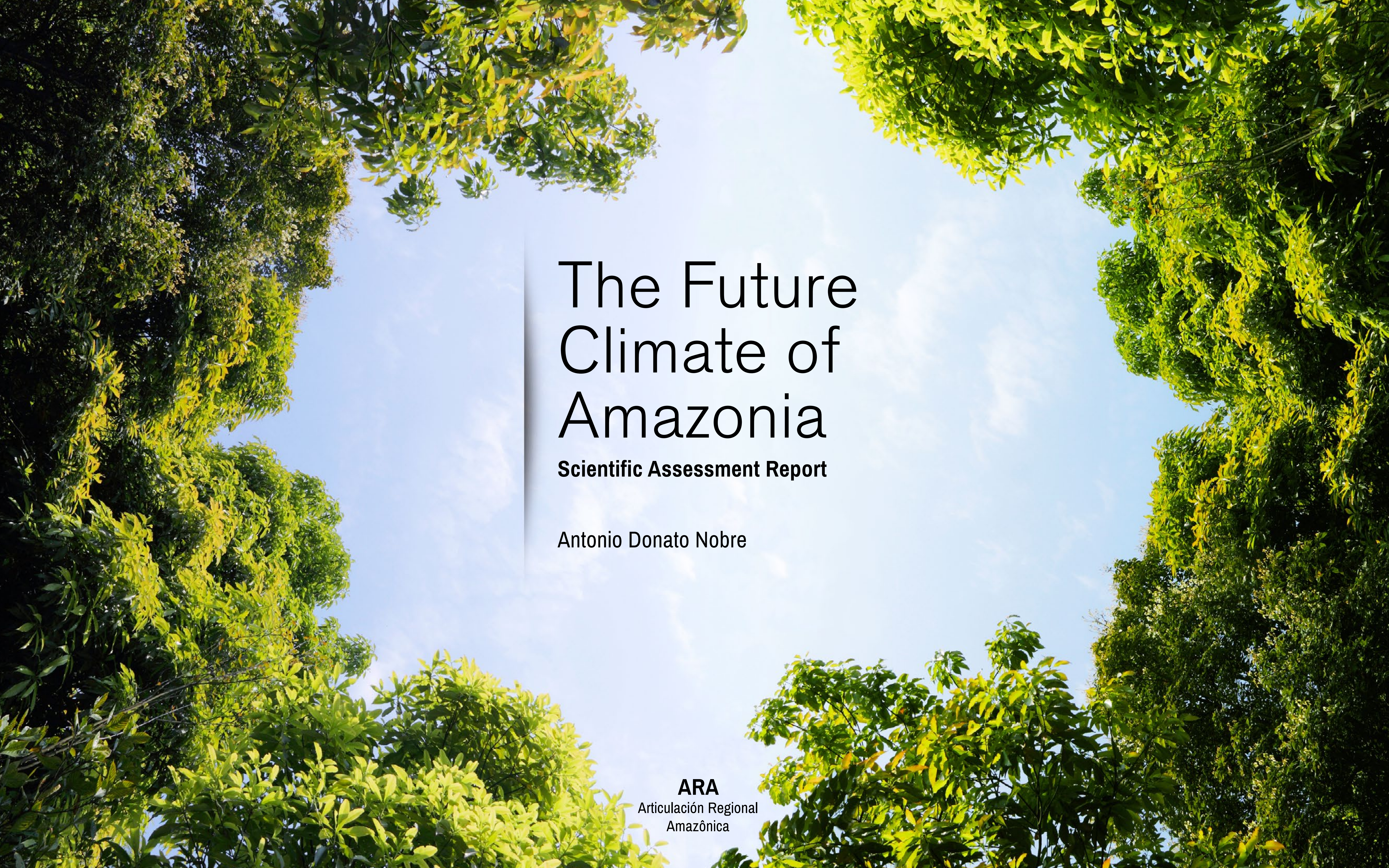

The Future Climate of Amazonia

Scientific Assessment Report

Antonio Donato Nobre

ARA
Articulación Regional Amazônica

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1st edition

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** The Earth System Science Center (Centro de Ciência do Sistema Terrestre) is a new department at INPE for interdisciplinary research on the Earth as a System.

Executive summary

This assessment of the future of the Amazon's climate consists of a concise review and synthesis of the scientific literature combined with an analytic interpretation of the key issues on the subject.

While focusing on the science, the report is couched in accessible language and adopts a holistic perspective, seeking to put numerous sources and expert analyses into a single coherent picture of the Amazon ecosystem.

The report seeks to trace the climatic potential of the world's greatest remaining rainforest, its functions critical to human society and its destruction through deforestation and fire. It further discusses what needs to be done to stop the runaway train that the climate has become since human occupation in forest areas.

Since the subject is vast, it needs to be examined in chronological sequence.

❶ The text begins with an overview of the key factor in geological history: *the network of Amazonian biodiversity, which developed its current functional capacities over tens of millions of years.* Life processes that operate in rainforests have developed an almost incomprehensible complexity, with an astronomical number of organisms working together like gears linked into a phenomenal environmental regulation machine.

❷ It goes on to describe the capabilities of the rainforest in its virgin state: *the Amazon forest -the green-ocean*[1]*- and its relationship with the atmosphere -the gaseous-ocean-, with which it exchanges gases, water and energy, and with the Atlantic -the blue-ocean-, the primary source and final repository of the water that irrigates the continent.* Ever since the studies of Humboldt[2], modern science and traditional indigenous knowledge have clarified important mysteries regarding the powers of the great rainforest over the elements that make up the Earth's climate. We explore five discoveries important to Amazonian ecohydrology.

Unraveling the mysteries of the Amazon

The first mystery involves the humidity that the rainforest maintains in moving air, and which brings rain to mainland areas that are located far from the oceans. This occurs due to the innate ability of trees to transfer large volumes of water from the soil to the atmosphere through transpiration.

The second mystery concerns the formation of abundant rainfall in clean air. Amazonian trees emit volatile substances that act as precursors of condensation nuclei for water vapor. The efficiency of these particles in cloud nucleation results in benign and bountiful rainfall.

1 The term *green-ocean* describes the ocean-like characteristics of this continental expanse covered by dense forests. The importance of this novel concept lies in its suggestion of a forest surface, stretched out below the atmosphere, where vastness, wetness and exposure to wind closely resemble characteristics akin to the actual oceans.

2 Alexander von Humboldt, influential German scientist-naturalist, who explored the Americas at the turn of the 18th century to the 19th century, considered the father of sciences such as geography, physics, meteorology and ecology.

The third mystery is related to the rainforest's capacity to survive climatic cataclysms and its formidable powers to sustain a beneficial hydrological cycle, even under unfavorable external conditions. According to the biotic pump theory[3], profuse tree transpiration, combined with very strong condensation in the formation of clouds and rainfall – a condensation far greater than that which occurs over adjacent oceans – leads to a reduction in atmospheric pressure over the forest which, in turn, draws moist air over the oceans inland, maintaining rainfall levels under most circumstances.

The fourth mystery explains why the southern portion of South America on the eastern side of the Andes is not a desert, as is the case with other areas at the same latitudes both west of the Andes and on other continents. The Amazon rainforest not only keeps the air moist for its own purposes, but also exports water vapor via aerial rivers, which carry the water that will produce the abundant rainfall that irrigates distant regions during the summer months.

The fifth mystery provides the reason why the Amazon and the oceans nearby do not allow certain atmospheric phenomena, such as hurricanes and extreme weather events, to propagate. Evenly distributed condensation over the wrinkled forest canopy precludes the concentration of wind power in damaging vortices like hurricanes or tornadoes on land, while the depletion of atmospheric moisture by lateral transport from over the ocean deprives the storms of their food (water vapor) in the oceanic regions adjacent to big forests.

All these effects combine together to make the majestic Amazon rainforest the very best and most valued partner for all human activities that require measured amounts of rain, a mild climate, and protection against extreme events.

❸ The report continues with a description of the effects of deforestation and fire on climate: *the devastation of the Amazon rainforest generates a dramatically inhospitable climate.* Over 20 years ago, climate models predicted various harmful effects of deforestation on the climate, and these have been confirmed by observations. Among these effects are drastic, widespread decreases in forest transpiration, changes in the dynamics of clouds and rain, and the extended duration of the dry season. Other side-effects that had not been predicted, such as the damaging effects of smoke and soot on rain processes, have also been observed, even over undisturbed *green-ocean* rainforest areas.

The damage inflicted on the Amazon climate by deforestation, fire, smoke and soot is already glaringly apparent in both scientific field measurements and in leading climate-modelling scenarios. Analysis based on updated climate models and on new physical theory predicts a worse future. The major factor affecting climate that emerges from this analysis is the severe cumulative extent of deforestation, an area measured up to 2013 in the Brazilian Amazon at nearly 763,000 km^2 (the combined area of two Germanys or two Japans). This surface measurement, furthermore, needs to be added to the impacted area of the little studied and seldom-mentioned extent of forest degradation (estimated to exceed 1.2 million km^2) that is likely to be a factor influencing climate.

❹ The report continues by relating the *green-ocean* rainforest and deforestation in the context of longer periods of time: *vegetation-climate equilibrium teetering on the brink of the abyss.* Climate models that are interactively linked to vegetation models can be used to explore which surface-areas of different types of vegetation and what climate conditions are capable of generating stable climate-vegetation equilibria.

For Amazonia, current models project the possibility of two equilibrium points: one that favors the forest (humid, the current and historical state of the Amazon basin) and another that favors the savanna (drier, the current conditions in the cerrado[4] -- a potentially bleak future for the Amazon basin).

A point of concern behind these modeling exercises is the clear indication that a reduction of approximately 40% of the rainforest may trigger a large-scale transition to a savanna equilibrium, in time

3 (Makarieva & Gorshkov, 2007) Biotic pump of atmospheric moisture as driver of the hydrological cycle on land.
4 N. of T. The "cerrado" is a type of savanna found in the Brazilian territory

eliminating even forests that have not been felled. Current clear cutting deforestation in the Brazilian Amazon corresponds to approximately 20% of the original forest cover, and forest degradation is estimated to have disturbed the remaining forest to varying degrees, directly affecting an additional 20% or so of the original area.

❺ The final section of this report recommends a mitigation plan that is based on a radical reversal of both past and expected future damage: *a war effort*. The rainforests of Amazonia are essential to sustaining the global climate and the security of future generations. Fortunately, advances in the sciences make this "war" a challenge than can be successfully met.

Despite the difficulty in precisely separating the background effects of global climate changes from effects on a local- and regional-scale, there is no doubt that deforestation, forest degradation and associated impacts have already affected the climate both near and far from the Amazon. They have already taken a heavy toll, and threaten to become even more serious in the future, such that the only responsible option available to us is to act immediately and forcefully to combat the causes.

As a first initiative, there is a need for universal, facilitated access to scientific discoveries, in order to reduce pressure from the primary cause of deforestation: ignorance.

Second, it is necessary to stop the bleeding and destruction of the forest, i.e., to halt deforestation, forest degradation and fire immediately using any and all possible and ethical means. At the same time, bearing in mind the conclusion that accumulated deforestation and degradation are the most serious factors contributing to regional climate change, developing a large scale, effective effort to replant and restore the areas denuded of their forest cover becomes an urgent necessity.

Such an effort must have medium- and long-term perspectives that culminate in the regeneration of the original *green-ocean* Amazonian rainforest, essential as it is to the global climate. In view of this, governments can, should and need to take the lead in orchestrating a massive mobilization of people, resources and strategies so we can make up for lost time.

In conclusion, while underscoring the urgency of actions to protect and restore the great Amazon rainforest, this report identifies real viable opportunities for us to trace new pathways to a future in which a renewed and protected rainforest can continue to provide fundamental ecological support for human activities both within and beyond the Amazon.

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Contents

Introduction

Forest *technology*[5] is irreplaceable

Loosely defined, the rainforest is a multicolored, extremely rich, structured living carpet. It is an extravagant colony of organisms that climbed out of the ocean 400 million years ago and migrated to land. Conditions inside forest leaves resemble primordial marine life. The rainforest canopy functions like a very elaborate adapted sea suspended in the air that contains a myriad of living cells. Having evolved over the last 50 million years, the Amazon rainforest is the largest technology park the Earth has ever known because each of its organisms (numbering among trillions) is a marvel of miniaturization and automation. At room temperature, using biochemical mechanisms of almost incomprehensible complexity, life continually processes atoms and molecules thereby determining and regulating the flow of substances and energy.

Forests condition the climate according to what suits them best and thereby generate stability and comfort, a shelter that enables human societies to flourish.

The comfortable climate that we enjoy on Earth, which is unknown on other celestial bodies, can be largely attributed (in addition to many other capacities) to the living organisms capable of performing photosynthesis. Carbon dioxide (CO_2) serves as food for plants, acting as the raw material that is transformed, via biochemical processes using both light and water, into wood, leaves, fruits and roots[6]. When plants consume CO_2, its concentration in the atmosphere decreases. When this happens, the planet initially cools down, reducing plant growth and consumption of CO_2. The subsequent accumulation of CO_2 leads to global warming and thus the process continues, following an oscillating cycle of self-regulation[7]. In this way, plants work as a thermostat that responds to temperature fluctuations by adjusting the concentration of CO_2, the primary greenhouse gas in the atmosphere after water vapor. However, this temperature regulation via the measured consumption of CO_2 is only one of many of life's mechanisms that result in favorable environmental regulation.

As will be seen in this work, rainforests are much more than an agglomeration of trees, a passive repository of biodiversity or simple carbon storage. Their living technology and dynamics of interaction with the environment gives them a certain power over the elements, an innate and resilient ability to condition the climate. Thus, forests condition the climate according to what suits them best and they thereby generate stability and create a comfort zone, a shelter which enables human societies to flourish.

South America is a continent privileged by the extensive presence of megabiodiverse forests. It is no coincidence that this continent had, and still has, one of the most favorable climates compared to other landmasses. However, over the last 500 years, most of the native

5 For lack of better term, the metaphorical use of *technology* wants to indicate a (non human) natural dimension of incredible complexity and sophistication existing in living systems, which operates automatically at nano-scale (billionths of a meter), so to create and maintain habitability and comfort. Arthur C. Clark third law states, "Any sufficiently advanced technology is indistinguishable from magic." Nature's technology is inconceivably advanced.
6 **Molecular biology animations**: http://www.johnkyrk.com/index.pt.html, in English; several languages available.
7 **Biotic Regulation of the Environment**: http://www.bioticregulation.ru/, in English.

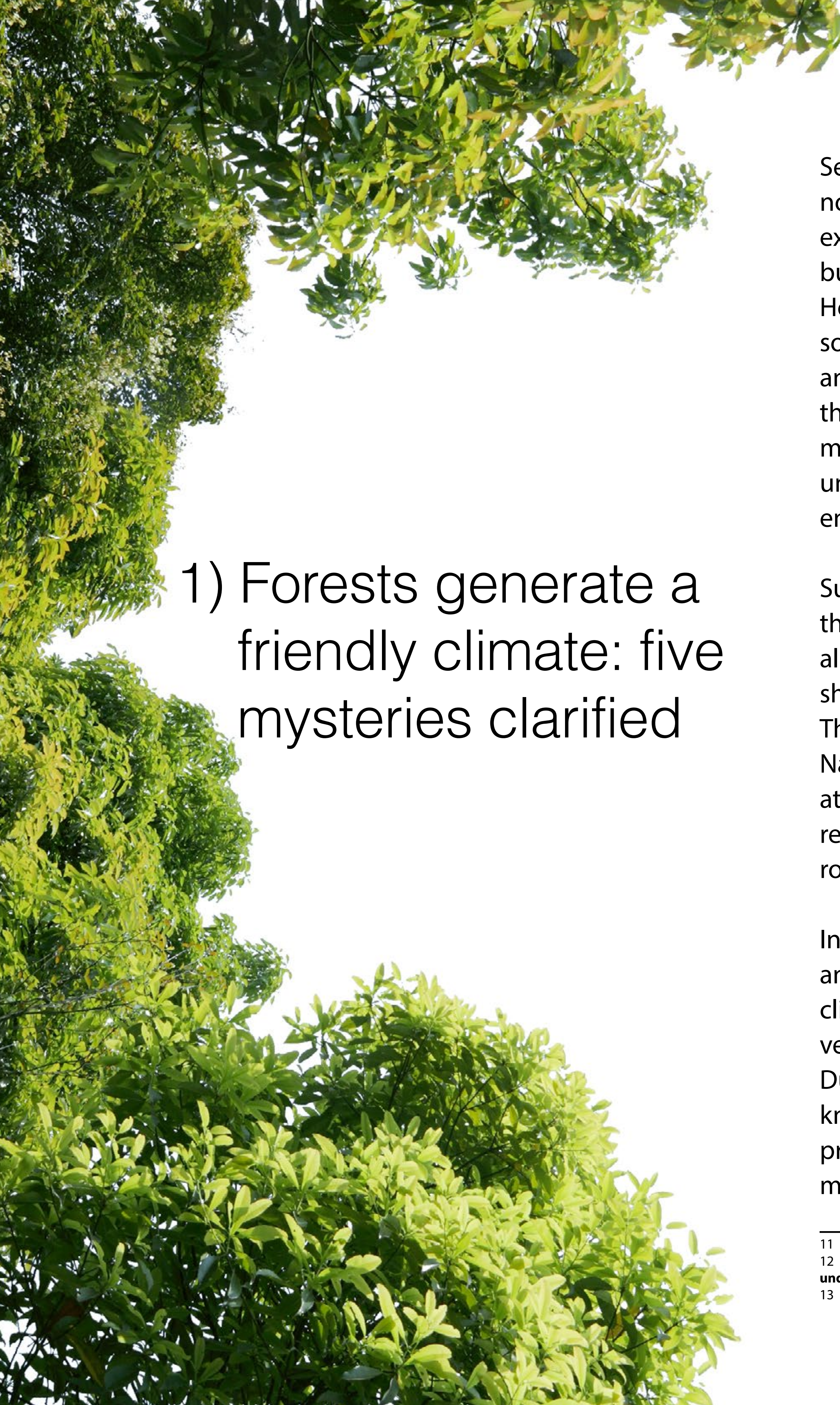
vegetation outside the Amazon basin has been annihilated. For example, the Atlantic Forest has lost more than 90% of its original coverage. Though perceptible, the effect of this historical deforestation on the climate has been less noticed than one would expect because the warmth and humidity of the wet *shadow* of the Amazon rainforest has kept the continent reasonably protected from extreme weather and maintained a mild climate. However, over the last 40 years, the last great rainforest, source of the atmospheric water that supplies most of the continent, has suffered relentless deforestation. Coincidentally, losses due to natural disasters induced by climate anomalies have increased, as much due to an excess of rain, heat and wind as to a lack of precipitation (droughts)[8].

The Andean regions, and even the Pacific coast, which depend on glaciers for their water supplies, may be under threat in the near future because of accelerated snowmelt induced by climate warming and because nearly all the rain that falls on the highest mountains, and replenishes the glaciers every year, originates from water vapor emitted by the Amazon forest[9]. East of the Andes, dependence on the Amazon hydrological cycle is immeasurably greater.

The savanna regions in the central-southern portion of this region, today home to one of the world's largest production belts of grains and other agricultural goods, also receives water vapor from the Amazon rainforest that provides regulated, benign rainfall[10]– agriculture's prime ingredient. The tongues of vapor that emerge from the Amazon during the summer bring essential rainfall and other beneficial influences to southeastern and southern Brazil (where South America's largest production infrastructure is located) and other areas, such as the Pantanal and the Chaco, Bolivia, Paraguay and Argentina's agricultural regions.

This study will first explain what we know on how the Amazon rainforest works and how it is able to exist and to persist through geological eras. Then it will show the effects on the climate that have already been caused by the ongoing destruction of the natural system and predictions on what is still to come. Finally, the text will explore the threats to climate balance that the alterations already in course may trigger by analyzing underlying climate risks from different perspectives.

8 (Marengo et al., 2013) Recent Extremes of Drought and Flooding in Amazonia: Vulnerabilities and Human Adaptation (Marengo et al., 2011) Extreme climatic events in the Amazon basin.
9 (Rabatel et al., 2012) Review article of the current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change.
10 (Willmot & Webber, 1998) **South American Climate Data**: http://climate.geog.udel.edu/~climate/, in English.



1) Forests generate a friendly climate: five mysteries clarified

Seeking to elucidate mysteries, a scientist's work does not differ greatly from a detective's investigations. They explore clues, analyze evidence, develop theories and build up models. In the thrilling deductions of Sherlock Holmes, the most intricate cases culminated in simple solutions. The reality of the natural world appears rich and complex, full of mysteries and secrets. However, the scientific method, spiced by fascination and humanized by childish curiosity, opens the gates towards understanding some of the most mysterious phenomena that affect our daily lives.

Such phenomena, when clarified and explained in their simplest forms, democratize scientific knowledge, allowing for the development of a new and exciting shared awareness about the world that we inhabit. There are still many mysterious secrets hidden away by Nature about how the forest works. Here, we will look at just five of them, mysteries that have been solved in recent decades and are crucial for understanding the roles of forests in generating a friendly climate.

In their eagerness to model the colossal flows of mass and energy using computers configured to simulate climate, meteorologists initially paid little attention to vegetation cover. This approach has radically changed. Due to a large and growing body of evidence, we now know the vital role vegetation plays in many climate processes. Nearly all climate models, as well as the most complex models of the earth system, now include elaborate representations of vegetation. Scientific findings about the determining role of forests in local-, regional- and global-scale cycles of water, energy, carbon and other variables apply to all natural forests. However, here we are going to focus more on the rainforests of South America, especially the Amazon.

Due to a large and growing body of evidence, we now know the vital role of vegetation in many climate processes.

All climate-modeling studies consider the Amazon basin as a whole. However, because there are more data available for the Brazilian Amazon[11], most scientific studies have been conducted in this region, especially for monitoring deforestation. Given the importance of the entire Amazon basin, i.e., the so-called Pan-Amazonia, and because the atmosphere and rivers do not care about political boundaries, future observations, mapping studies and analyses must break through national boundaries, following the example of projects such as RAISG, with its extensive, integrated surveys on human pressure on the Amazon[12].

1.1) Recycling of moisture: forest geysers

Three hundred years after the European invasion of the Americas[13], the aura of a Garden of Eden in the tropical jungles had already lost its romantic appeal, possibly because of the greedy Spanish conquistadores' horror of the green hell, an endless, monotonous and dangerous labyrinth that inspired more fear and despair than

11 Defined within what was delineated as Legal Amazon by decree during the Brazilian dictatorship (1964-1985).
12 **RAISG** Red Amazónica de Información Socioambietal Georreferenciada [Amazonian Network of Georeferenced Socio-environmental Information]: http://raisg.socioambiental.org/, in Spanish; **Atlas Amazonia under pressure**: http://raisg.socioambiental.org/system/files/Amazonia under pressure16_05_2013.pdf, in English.
13 (Gambini, 2000) Espelho índio: a formação da alma brasileira [Indian mirror - the making of the Brazilian soul].

fascination. In the 19th century, thanks to scientific naturalists, the fascination was rekindled but now tinged with a rational appeal. Alexander von Humboldt, the acclaimed, influential German scientist and naturalist who explored the Americas in the late 1700s/early 1800s, is considered the father of sciences such as physical geography, meteorology and ecology. He used the term *Hylaea* [from the Greek, wild forest] for Amazonia and, with the richness and enchantment of his detailed descriptions, he inspired generations of naturalists, including Darwin. Humboldt was the first to suggest a connection between forests, air humidity and climate.

However, in the early 20th century, the polymath Euclides da Cunha, a prolific Brazilian author and military man, broke the spell of scientific naturalism with his disillusioned descriptions of the *hylaea*. His disciple Alberto Rangel, who, like his master, was also moved by the misery of the rubber tappers and hardships of life in the jungle, revived the prospect of damnation of the Spanish invaders in the book *Inferno Verde* (Green Hell) and irreversibly dispelled the image of a green paradise. Their verbal bigotry against the wilderness *habitat*, backed by their self-confessed ignorance as to the intrinsic value of the forest, in conjunction with the failure of the rubber boom, most likely allowed their legacy of values to influence hearts and minds of future generations.

How much of the subsequent urge to "occupy" the Amazon, with the remorseless eradication of the forest, had its roots in this story? Euclides da Cunha, prefacing his disciple's book, discredits Humboldt's holistic approach (*"the epistemology of 'Amazonian science' will flourish if one worries less about revealing the entire hylaea"*) and anticipated the reductionist demand to come[14].

The recycling of moisture from the rain by forest evaporation keeps the air humid for over 3,000 km inland.

Studies that finally revealed the secrets of the great forest were slow in coming. Seeking to test preliminary water balance calculations for the Amazon[15] that indicated significant water recycling, Enéas Salati led observational studies on rainfall and evaporation in the 1970s that unequivocally demonstrated how the forest via moisture recycling keeps the air humid for over 3,000 km inland[16].

However, these findings left numerous questions unanswered, i.e., where, how much, how, why and with what implications. Unknowingly adopting Euclides da Cunha's reductionist suggestion, in the three decades following Salati's studies, over two dozen major research projects[17] - bringing together hundreds of scientists and using many laboratories, sophisticated instruments, towers, airplanes, boats, satellites, supercomputers and other scientific tools - have produced thousands of articles, dozens of books and numerous databases, primarily containing information that is difficult to interpret when considered in isolation.

It is said that the "present-day scientist" is one who studies more and more about less and less until he knows everything about nothing. It is ironic that, 200 years later, the most productive way of making sense of the enormity of these research studies is precisely to resume Humboldt's holistic approach, articulating the wealth of loose data and building an integrated and functional narrative about the astonishing concentration of life in the forests of Amazonia and its power over the elements.

Let us see how we can capture the spectacular aspects of just how the forest works by following the path water takes from the atmosphere, through the deepest intimacy of plants and back into the atmosphere again.

Transpiration: plants do not wear deodorant

Plants sweat. The evaporating water cools both the leaves and the environment. However, transpiration in plants is much more important than just that. Transpiration promotes the suction of nutrient-rich soil water by the roots and up through the trunk into the leaves. It enables leaves to open their microportals to the atmosphere (stomata), allowing water vapor to leave but also allowing the most essential of gaseous fertilizer to enter, i.e., CO_2. The scents produced by plants, i.e., the organic gases that play many roles in how the atmosphere and rainfall operate, are expelled along with the transpired water. Therefore, without transpiration, plants would no longer regulate their own wellness; they would cease to control the environment and would die from a lack of nutrients, including CO_2, and excessive temperatures.

14 Rafael Leandro reflects Euclides da Cunha's expression in that preface: *"the enormity of the forest can only be measured if partitioned… only in the late future will one know the secrets of Nature […] The definition of the last aspects of the Amazon will represent the conclusion of all natural history…"* (Leandro, 2009) Inferno Verde: Representação Literária da Amazônia na Obra de Alberto Rangel [Green Hell: Literary Representation of the Amazon in the Work of Alberto Rangel].

15 (Molion 1975) A climatonomic study of the energy and moisture fluxes of the Amazon basin with considerations of deforestation effects; (Villa Nova et al. 1976) Estimativa de evapotranspiração na Bacia Amazônica [Estimate of evapotranspiration in the Amazon Basin]; (Marques et al. 1977) Precipitable water and water vapor flux between Belem and Manaus.

16 (Salati et al, 1979) Recycling of Water in the Amazon Basin: An Isotopic Study.

17 **Research projects in the Amazon:** ARME, NASA-GTE ABLE, ABRACOS, TRACE-A, RBLE, CAMREX, INPA-Max Planck, INPA-ORSTOM, PDBFF, PELD, LBA, LBA-EUSTACH, LBA-CARBONSINK, LBA-CLAIRE, LBA-ECO, LBA-Barca, LBA-DMIP, GEWEX, ISLSCP, GEOMA, PPBio, Rainfor, AmazonFlux, AMAZE, Amazon Pire, Amazalert, AMAZONICA, Changing Amazônia, ATTO, ACRIDICON-CHUVA, GreenOceanAmazon etc. Within the great LBA project alone, 217 research subprojects were developed over 16 years of operation.

After clouds precipitate their precious liquid over the forest, a lot of water trickles through the canopy and infiltrates the permeable forest bed where it is stored in porous soil or, deeper down, in large aquifers acting as veritable underground oceans of freshwater.

The water from the soil begins its return journey to the atmosphere by being absorbed by deep and sophisticated suction devices, i.e., plant roots. It then defies gravity and rises to heights of 40 to 60 m (or more) in elaborate pipelines in the xylem of tree trunks. Finally, the water goes through the laminar evaporating structures of the leaves, which are versatile chemical solar panels capable of absorbing energy from the sun and taking advantage of the wind's caresses to transpire and transfer copious amounts of water vapor into the atmosphere, thus completing the vertical cycle that began with the rain.

A large tree can pump from the soil and transpire over a thousand liters of water in a single day.

A large tree can pump from the soil and transpire over a thousand liters of water in a single day[18]. Amazonia is home to hundreds of billions of trees in its forests. Twenty billion tons of water are transpired per day by all the trees in the Amazon basin[19]. As a whole, these trees - those benevolent silent green structures of nature -, act like *geysers* and spout a vertical river of vapor into the air that is even greater than the Amazon River.[20]

Vapor *geyser*: greater than the Amazon River

Seeking a simple way to quantify the massive forest transpiration suggested by the studies of Salati and others, we made revealing calculations in 2007 in conjunction with Adriana Cuartas. Using evaporation data collected from flux towers as part of the LBA project (an average of 3.6 mm per day, or 3.6 liters per m^2), we estimated the total amount of water flowing daily from the soil to the atmosphere through the trees. The calculation for the whole rainforest, covering 5.5 million km^2 in the Amazon basin, resulted in the astronomical number of 20 billion tons of water transpired per day (or 20 trillion liters). This would be over 22 billion tons if we consider all forests in equatorial South America and 25 billion (or more) if we considered the forests in their pristine state in 1500[19]. For comparison purposes: the volume of water discharged by the Amazon River into the Atlantic Ocean is slightly more than 17 billion tons per day[20].

Twenty billion tons of water is transpired per day by all the trees in the Amazon basin.

Just like a building with many floors, one square meter of ground in the Amazon may support up to 10 square meters of intricate foliar surface distributed at different levels in the canopy. This explains the fact that a forested land surface can evaporate as much water as the liquid surface of an ocean or a lake (where 1 m^2 of evaporating surface coincides with the same 1 m^2 of geometric surface).

Duly corroborating these amazing facts, a study recently published in the scientific journal *Nature*[21] has advanced our understanding of the extraordinary importance of global vegetation in transferring water back to the atmosphere: nearly 90% of all water that reaches the atmosphere from the continents does so via plant

18 Assuming a crown area with a radius of 10 m, 324.2 m^2 x 3.6 liters/m^2 = 1131.1 transpired liters in one day.
19 Based on the recent forested area in the Amazon river basis, 5.5 x 10^{12} m^2 x 3.6 liters/m^2 = 19.8 x 10^{12} liters (~20 x 10^9 tons). The forest area in the Amazon (*sensu latissimo* Eva et al, 2005, A proposal for defining the geographical Boundaries of Amazônia), including wet, dry and flooded forests = 6,280,468 km^2, or 6.280468 x 10^{12} m^2 x 3.6 liters/m^2 = 22.6096848 x 10^{12} liters (22.61 x 10^9 tons). Based on the historical area covered with forest (area with forest in 2004 – Eva et al., 2005- more clear cut deforestation until 2004, Alves 2007) = 6,943,468 km^2, or 6.943468 x 10^{12} m^2 x 3.6 liters/m^2 = 25 x 10^{12} liters (25 x 10^9 tons).
20 The flow rate of the Amazon River at the mouth is 2 x 10^5 m^3/second x 86400 seconds/day = 17.28 x 10^9 m^3/day.
21 (Jasechko et al., 2013) Terrestrial water fluxes dominated by transpiration.

Plant transpiration transfers nearly 90% of all water that reaches the atmosphere from the continents

transpiration; only slightly more than 10% reaches the atmosphere through simple evaporation without the mediation of plants. Because this transfer by transpiration occurs due to substantial surface energy absorption, plants are able to interfere greatly with rainfall, winds and the weather.

Water transfer to the atmosphere requires energy. Let us look at a close parallel. To generate much-needed electricity, there is much talk about harnessing energy from the waters of the Amazon. However, hydraulic energy from falling river water only exists because that water was lifted up and transported by the atmosphere to the upper headwaters. The transpiration of trees, which is a vital link in the water cycle, consumes solar energy as water is pumped out of the soil and during transpiration. The trees thus function as elevators that lift and launch water high into the atmosphere; this water can later return to the ground as rain, transferring a portion of the built-in solar energy in the water vapor to potential energy in the water that fills the reservoirs of hydroelectric dams.

1.2) Cloud nucleation: the *pixie dust* over the green ocean

Returning colossal volumes of water vapor into the atmosphere is only the first part of the recipe to make and maintain plentiful, benign rains. In 1999, one of the first studies using aircraft and observations from the TRMM[22] satellite, which was conducted as part of the LBA project, found that the air in the lower atmosphere (troposphere) in the Amazon is as clean of dust as the air over the ocean, where dust sources are few. This study also found that typical Amazonian clouds closely resemble maritime clouds. This unusual similarity inspired those researchers to nickname the Amazon the "green-ocean"[23]. The term *green-ocean* describes the ocean-like characteristics of this continental expanse covered by dense forests. The importance of this novel concept lies in its suggestion of a forest surface, stretched out below the atmosphere, where vastness, wetness and exposure to wind closely resemble characteristics akin to the actual oceans.

Climate power of the forest

How much energy from the Sun is consumed to evaporate 20 trillion liters of water per day? To get an idea of the magnitude of energy involved in transpiration within the Amazon, let us compare this to the energy produced by hydroelectric dams. Evaporating one gram of liquid water consumes 2.3 kilojoules of solar energy. To convert this into electrical hydro power, imagine a giant kettle – one of those you plug into a power outlet – that could hold this water volume. How much electricity would be needed to boil and evaporate all this water? The Itaipu power plant, with its 14,000 megawatts of power, would need to generate electricity at maximum capacity for 145 years for the kettle to evaporate the amount of water equivalent to that transpired in just one day in the Amazon. Alternatively, to compete with the Amazon's trees and do the job in one day, it would be necessary to combine the electricity produced by 50,000 power plants like Itaipu (or 200,000 like Belo Monte on the Xingu river). This comparison shows clearly that the greatest of human structures are microscopic beside the climate power of the forest.

However, there was a mystery in this similarity because most of the blue ocean tends towards aridity, with very little rainfall whilst most of the *green-ocean* receives constant torrential rainfall. This rainfall used to be so plentiful that before the advance of deforestation, it was often said that there were only two seasons in the Amazon, wet and wetter. Now, there is a pronounced dry season, and the duration of the wet season diminishes progressively[24].

Green ocean: the Amazon atmosphere has air as clear of dust as the atmosphere over the blue ocean.

Clouds are clusters of small water droplets suspended in the air. Visible droplets condense from water vapor, which is invisible to the naked eye, at sufficiently low temperatures. However, temperature alone does not initiate the condensation process. A solid or liquid surface that works as a "seed" for the deposition of vapor molecules must also initially be present. These seeds, or condensation nuclei, are generally atmospheric aerosols: dust particles, pollen, salt grains, soot and many others.

However, aerosols are found in low concentrations over the *green-ocean*, a condition that is similar to the blue ocean. If the cleanliness of the air can be accredited, on the one hand, to the effect of a carpet of damp forest keeping the dust down and, on the other hand, to the cleansing of the air by the constant rainfall over the *green-ocean*, how does such abundant rainfall occur without the usual seeds for nucleation?

When studying carbon dioxide exchanges using flux towers, Brazilian scientists from INPA and USP and European

22 **Tropical Rainfall Measurement Mission**: http://trmm.gsfc.nasa.gov/, in English.
23 (Williams et al., 2002) Contrasting convective regimes over the Amazon: Implications for cloud electrification.
24 (Marengo 2011) The drought of 2010 in the context of historical droughts in the Amazon region.

scientists from the Netherlands, Germany and Italy collaborated on the LBA project to also investigate the exchange of other carbon-containing gases produced by plants and to assess if these gases are important for these exchanges. These other gases are the "scents" of the forest, and are also called biogenic volatile organic compounds (BVOCs[25]). Just as an open perfume bottle loses liquid via evaporation and the perfume is diffused into the ambient air, a variety of organic substances evaporate from leaves and enter the atmosphere.

In humid air and sunlight, plant scents form a very fine dust with an affinity for water; these are the cloud condensation nuclei.

In terms of mass, the amount of carbon lost to the atmosphere through these organic gases is small. However, a group led by Meinrat Andreae from the Max Planck Institute, which studies the chemistry of gases in the atmosphere, investigated the effects of these aromas when mixed with Amazon air and unlocked the mystery of cloud nucleation in this region[26]. BVOCs (such as isoprene, terpenes and many others), in a humid atmosphere and in the presence of solar radiation, oxidize and precipitate to form very fine dust particles with an affinity for water (hygroscopic) that act as efficient cloud condensation nuclei. Poetically speaking, this is the *pixie dust* that magically appears in the moisture-laden air, and causes rain to bucket down from low clouds, i.e., the watering cans of the Garden of Eden. While BVOCs exist in the form of gas dissolved in the air, the rain does not wash them out. They are only washed out when they oxidize and precipitate as aerosols that act to form rain. However, there are always more BVOCs available to form more *pixie dust* for the next rain shower.

In addition to promoting plentiful, gentle rains, other biochemical mechanisms that are similar to those that produce BVOCs act as "chemical brushes" for the atmosphere. Under Amazonian conditions, hazardous pollutants (such as ozone) are removed from the air. In the 1980s, in the first studies of atmospheric chemistry using specially equipped aircraft, it was found that the air in the lower atmosphere over the Amazon contained less ozone (and was therefore healthier) than air in the most remote regions on Earth (such as Antarctica). In subsequent decades, other research projects have pointed out the role of trees in cleaning the atmosphere[27]. From these and other ongoing studies, it can be suggested that Amazonian plants use some form of vitamin C as an antioxidant to remove from the air gases that are harmful to life.

1.3) Biotic moisture pump: donate water to receive rain

In 2005, at the peak of the most serious drought ever to hit the Amazon till that time, we worked on integrating data encompassing the first six years of the LBA project[28]. After reviewing the evidence drawn from

25 ***B****iogenic* *Volatile* ***O****rganic* ***C****arbons*: these compounds are considered biogenic because they are synthesized by living organisms, like the scents of plants. There are other volatile organic compounds that are non-biogenic, which are simply called VOCs, e.g., paint solvent.

26 (Pöschl et al., 2010) Rainforest aerosols as biogenic nuclei of clouds and precipitation in the Amazon, (Clayes et al., 2004) Formation of secondary organic aerosols through photooxidation of isoprene. Release: Max Planck Institute news, **Astonishing Discovery over the Amazonian Rain Forest**: http://www.mpg.de/495047/pressRelease20040224, in English.

27 For example: (Rummel et al., 2007) Seasonal variation of ozone deposition to a tropical rain forest in southwest Amazonia.

28 (Nobre, 2005) Is the Amazon Forest a Sitting Duck for Climate Change? Models Need yet to Capture the Complex Mutual Conditioning between Vegetation and Rainfall.

observations and model results discussed in several studies, I pondered the trending question at the time: with global warming, will the rainforest in the Amazon wither and die?

Over thousands[29] or, most likely, even millions of years[30], the South American rainforest has evolved its lush biota with no signs of having ever been halted by extreme weather, such as drought or freezing. However, over the same time period, it is unlikely that the impact of external climate on the continent has remained benign, especially considering cosmic interferences and their known relationships with pronounced global climate changes[31].

In the face of external climate adversity, how could this magnificent biome resist extinction? There are sufficient lines of evidence indicating that the biosphere is able not only endure but can also change, modulate and even regulate its own environment[32].

A forested region generates far more condensation in the form of rain production than the adjacent ocean and draws air from the sea to the land, which brings more rain to the forested area.

The rainforests of South America are among the most dense, diverse and complex terrestrial biomes on the planet. Based on rainfall mechanisms in the *green-ocean*, one can imagine how these forests can regulate climate. Controlling rainfall also means controlling convection, which means that these vast forests interfere with a powerful conveyor belt of mass and energy: the Hadley circulation[33]. By regulating rainfall, biology may set the strength of the trade winds from the Atlantic, drawing the required moisture inland from the open ocean.

During the same period, Victor Gorshkov and Anastassia Makarieva, broadening their theory about biotic regulation of the environment[34], examined the mechanisms linking plant transpiration with physical effects in the atmosphere. From the surprising findings of their analysis, they developed the biotic pump of atmospheric moisture theory[35]. This theory explains how transpiration and condensation processes that are mediated and manipulated by the trees change the atmospheric pressure and dynamics, resulting in increased moisture supply from the ocean moving inland where there are forested landmasses.

Makarieva et al. found that water vapor condensation in the atmosphere generates a local decrease in pressure and produces dynamic power that accelerates the winds across the resulting pressure gradients[36]. The crucial point of the theory is that surface evaporation gradients – hand in hand with decisive condensation in clouds - are the primary factors that determine the direction and intensity of the rain-bringing winds, much more so than surface temperature gradients.

Thus, a forested region that evaporates as much or even more water than an adjacent ocean surface – and that generates far more condensation in the form of rain production – will draw moisture-laden air currents inland from the sea, precisely bringing rain to the forested area. By contrast, if the forest were removed, there would be much less evaporation inland than over the adjacent ocean and a consequent decrease in condensation, thus resulting in a reversal of net moisture flow, i.e. from land to sea[37], creating a desert where once there was a forest.

Among the predictions based on the biotic pump theory put forward by Makarieva and Gorshkov, one hypothesis suggests that droughts in native forests are counterpoised by vigorous transpiration from the trees. This prediction goes against common sense because anybody knows that if you leave a pot-plant unwatered for a few days, the plant will wither and may even die.

Amazonia, the world's heart

How can we understand water circulation by looking at the landscape? Water irrigates and drains the soils in a similar way to blood, which irrigates and drains body tissues. If rivers are analogous to veins, draining used water and returning it to its origin in the ocean, where are the arteries of the natural system? The arteries are the aerial rivers, bringing us fresh water that has been renewed via ocean evaporation. To complete the circulatory system, only the heart is missing; it is the pump that drives the flow of the aerial arteries. The biotic pump theory explains that the power propelling the winds and channeling the aerial rivers must be attributed to the great rainforest, which functions as the heart of the water cycle.

29 (Baker et al., 2001) The history of South American tropical precipitation for the past 25,000 years.
30 (Hooghiemstra et al., 2002) Evolution of forests in the northern Andes and Amazonian lowlands during the Tertiary and Quaternary.
31 (Berger and Yin, 2012) Astronomical Theory and Orbital Forcing.
32 (Foley and Costa, 2003) Green surprise? How terrestrial ecosystems could affect earth's climate; (Gorshkov et al., 2004) Revising the fundamentals of ecological knowledge: the biota–environment interaction; (Pielke and Avissar, 1998) Interactions between the atmosphere and terrestrial ecosystems: influence on weather and climate.
33 (Poveda and Mesa, 1997) Feedbacks between hydrological processes in tropical South America and large-scale ocean-atmospheric phenomena.
34 (Gorshkov et al., 2000) Biotic Regulation of the Environment: Key Issues of Global Change.
35 (Makarieva and Gorshkov, 2007) Biotic pump of atmospheric moisture as driver of the hydrological cycle on land.
36 (Makarieva et al., 2013) Where do winds come from?
37 Already considering and excluding the effects of global circulation associated with inertial movements and accelerations.

This idea also contradicts the knowledge of ecophysiologists, who believe that when rainfall stops and the water content in the soil decreases, plants close their stomata and stop transpiring to retain water. At the same time, it provides a clue to the long-standing ecophysiological enigma: why photosynthesis has evolved to be so "wasteful" of water vapor.

Surprisingly, Scott Saleska et al. published observations that corroborate the theoretical predictions of Makarieva and Gorshkov in the scientific journal *Science*[38]. During the peak of the 2005 drought, the most affected parts of the Amazon were those that had "greened" the most, i.e., a greater number of new leaves had sprouted in tree canopies (as observed by the MODIS sensor on the Terra satellite) in areas where less rain had fallen (according to TRMM satellite records).

The findings of this study based on satellite images were already supported by surface-based measurements from the LBA project flux towers, which had observed no decrease in transpiration from trees during the dry seasons. This finding suggests that under drought conditions, trees with deep roots (and access to a large amount of groundwater) follow an internal program to maintain or increase transpiration. In this way, the transpiration of water vapor at surface levels, and the corresponding condensation in clouds, maintain the conveyor belt of moist air being transported from the adjacent oceans. The significance of this is that atmospheric water continues to be imported, outbalancing the drought and ensuring forest continuity. The biotic pump theory is steadily gaining acceptance[39] and already has observational evidence[40].

1.4) Aerial rivers: fresh water through airborne arteries

A glance at a world map reveals interesting arrangements and symmetries in the distribution of forests and deserts around the globe, with three specific belts that particularly attract our attention: a belt of forest around the Equator and two of desert around the Tropics of Cancer and of Capricorn. This geography of contrasting landscapes is easily explained by the Hadley Circulation[41].

Under the influence of the Hadley circulation, the south-central portion of South America should tend toward aridity.

The incident solar radiation in the equatorial zone is greater than at higher latitudes; therefore, due to physical effects, there is a great updraft of air in this region, which cools and leads to the formation of rain, favoring the proliferation of forests. The air that has risen and subsequently lost its moisture needs to go somewhere so, in both hemispheres, it moves toward the subtropics. When it descends again and warms up, this dry air absorbs moisture from the surface, which favors the creation of deserts.

However, there are exceptions to this general rule and the southern-central portion of South America is one

38 (Saleska et al., 2007) Amazon forests green-up during 2005 drought.
39 For example: (Sheil and Murdiyarso, 2009) How Forests Attract Rain: An Examination of a New Hypothesis.
40 (Poveda et al., 2014) Seasonal precipitation patterns along pathways of South American low-level jets and aerial rivers.
41 **Hadley cell definition**: http://en.wikipedia.org/wiki/Hadley_cell, in English.

Flying rivers: telling a lovely story

In 2006, contemplating the Amazon forest from the top of an LBA project study tower, we exchanged the first ideas that led to the adventure, research, outreach and environmental education project Rios Voadores [Flying Rivers] with aviator Gerard Moss[42]. With funding from Petrobras and the participation of Enéas Salati, a pioneer in studies on moisture recycling in the Amazon, as well as other leading scientists, Moss followed the water vapor rivers for years in his single-engine plane, collecting numerous samples for analysis, capturing the public's attention in the adventure he created. The project also did an extraordinary job in environmental education in schools and through the Internet, often posting the routes of flying rivers on social networks to show people how water is brought to them. The most valuable result from this project was its ability to touch people's emotional side through ludic stimulation, adventure and scientific engagement, awakening in them a feeling of appreciation for the environment, water and the forest.

of them. Influenced by Hadley Circulation, this region should tend towards arid conditions. You just need to look at the Atacama Desert, on the other side of the Andes, or the Namib and Kalahari deserts in Africa and the Australian desert. Latitudinally speaking, they are all aligned with the fortunate green area that is responsible for 70% of the continent's GDP, and forms a quadrangle bounded by Cuiabá to the north, São Paulo to the east, Buenos Aires to the south, and the Andes to the west.

Schools teach students that water evaporates from the sea, *"comes"* inland, falls as rain, is collected in surface rivers and returns to the sea. By making the connection between water evaporation at sea and its advection toward land, this simplistic water cycle concept is not incorrect, but explains almost nothing. Like, for example, why deserts exist or why water vapor from the sea heterogeneously moves inland onto the continents.

Salati et al., when comparing the chemical signatures[43] of oceanic water vapor entering the great theater of Amazonia with the corresponding signatures of runoff water returning to the ocean through the Amazon River, observed that a significant portion of the water that had come inland as vapor by the aerial channel did not leave by the terrestrial channel[44].

The authors concluded that the Amazon must be exporting this water vapor to other regions of the continent and irrigating water basins other than the Amazon. Preliminary analyses conducted at the time on rainwater collected in Rio de Janeiro found signs that some of it came from inland sources and not the ocean right close by. More specifically, this water had passed through the Amazon. This research group was the first to suggest that rains in South America outside the Amazon region could actually be fed by long range continental water vapor transport.

The concept of atmospheric rivers was introduced in 1992 by Reginald Newell and Nicholas Newell[45] to describe filamentary flows in the lower atmosphere capable of transporting large amounts of water as vapor, typically at greater volumes than those carried by the mighty Amazon River (which has a flow rate of 200 million liters per second, or 17 billion tons per day).

Aerial rivers connect the moisture-laden trade winds from the equatorial Atlantic with the winds that blow over the Amazon as far as the Andes, and from there, depending on the season, over to the southern part of South America.

Nearly three decades after Salati's findings, José Marengo et al.[46] described the circulation that connects the moisture-laden trade winds from the equatorial Atlantic with the winds that blow over the Amazon as far as the Andes, and from there, depending on the season, over to the southern part of South America. Although the authors framed their findings in the context of *low-level jets*, the concept is very similar to that of atmospheric rivers. As per their explanations, a system of monsoons similar to that in Asia also operates in South America. Due to the effects of the rainforest (forest *geysers*) and of the Andes (a 6-km high barrier), the persistent moist Amazonian air makes a bend near Acre and, during the summer, carries copious amounts of water vapor down to the afore-mentioned lucky quadrangle, countering the trend towards aridity in this region.

Josefina Arraut[47] et al. recently conducted a climatological review of aerial rivers over South America, estimating the associated vapor transport and introducing a new concept of "aerial lakes", places that accumulate atmospheric backwater and hold stocks of precipitable water vapor.

42 **Flying Rivers Project**: http://riosvoadores.com.br/english/, in English.

43 Defined by the use of tracers that carry isotopic signatures. Isotopes are said to be two or more atoms with the same number of protons but different masses. A good analogy is to think of twins with identical features except for weight. Isotopic signature is the numerical relationship between the immense multitude of atomic "twins" in a material or substance. Water can contain various combinations of oxygen isotopic twins (^{16}O and ^{18}O) and hydrogen isotopic twins (^{1}H and ^{2}H), generating water molecules with different masses. The proportion of these atomic twins that occurs in seawater, for example, changes with evaporation (the lighter ones float first) and with rain (the heavier ones precipitate first). Thus, when analyzing the isotopic signature of a water or vapor sample, it is possible to know if it came from the ocean or the forest.

44 (Salati et al., 1979) Recycling of Water in the Amazon Basin : An Isotopic Study; (Matsui et al., 1976) Isotopic hydrology in the Amazonia, 2, Relative discharges of the Negro and Solimões rivers through ^{18}O concentrations.

45 (Newell and Newell, 1992) Tropospheric Rivers? - A Pilot Study.

46 (Marengo et al., 2004) Climatology of the low-level jet east of the Andes as derived from the NCEP-NCAR reanalysis: Characteristics and temporal variability.

47 (Arraut et al., 2012) Aerial Rivers and Lakes: Looking at Large-Scale Moisture Transport and Its Relation to Amazonia and to Subtropical Rainfall in South America.

Extreme events: life's checks and balances

With global warming, there is greater accumulation of energy in the atmosphere, which increases the probability of more intense climate phenomena. This trend was predicted by meteorologists decades ago. However, the greater intensity and frequency of these occurrences is now being observed decades ahead of schedule. There must be a factor in the complexity of the climate system that can explain the acceleration of these effects. Geological records show that extreme climates have already occurred in Earth's history, long before mankind appeared. However, contrary to what one would expect after cataclysms, all evidence always point to a resilient stabilizing recovery that lessens the extremes. Purely geophysical systems do not have this ability. Only life and its self-regulatory processes offer satisfactory explanations for the Earth's climate history.[52]

With the concept of aerial rivers well established and gaining in credibility, Dominick Spracklen[48] et al. developed a new approach correlating a surface covered by vegetation that is exposed to air moving within an aerial river (measured by the cumulative leaf area index along the path) with rainfall downstream along the same path taken by that air mass. Specifically, an aerial river connects moisture-donating regions with moisture-receiving locations. Hence, forests that lie upstream are critically important. The authors found that the Amazon is in fact the *headwater* of the aerial sources of most rainfall in South America.

1.5) Wrinkled canopy: wind-break

Makarieva and Gorshkov[49] introduced a new physical definition for hurricanes, cyclones and tornados: *"...explosions reversed and prolonged in time due to the volumetric disappearance of water vapor in the atmosphere by condensation"*[50]. Paulo Nobre subsequently presented the authors with the following problem: *"The question that arises… is to understand why hurricanes do not develop over tropical forests, like the Amazon, where supplies of water vapor provided by the forest and their elimination, in the form of tropical rain, are so abundant."* [51]

The services that the forest provides to the climate include an insurance against destructive weather events, softening the force of wind-borne energy.

In response, Makarieva and Gorshkov showed why a large land surface covered by forest is, theoretically, an impediment to the formation of hurricanes and other anomalous weather patterns including droughts and floods. In their explanation, localized turbulent friction of the actively transpiring forest canopy, which results in uniform rainfall rates over large areas, and wind traction due to the biotic pump over larger distances greatly reduce the chance of forming storms such as tornadoes or hurricanes. Recorded hurricane paths confirm that a milder environment exists in areas covered by extensive forests and the oceans just nearby[53].

In addition to all the other services that forests provide for the climate, they even offer insurance against destructive weather events, softening the force of wind-borne energy. Other classic functions of forests in regulating the water cycle on land are well known, such as favoring groundwater recharge and flood mitigation[54], among many others.

48 (Spracklen et al., 2012) Observations of increased tropical rainfall preceded by air passage over forests.
49 (Makarieva et al., 2008) On the validity of representing hurricanes as Carnot heat engine.
50 According to the authors: *"The driving force of all hurricane processes is a rapid release, as in compressed spring, of potential energy previously accumulated in the form of saturated water vapor in the atmospheric column during a prolonged period of water vapor evaporation under the action of the absorbed solar radiation."* (Makarieva et al., 2014) Condensational power of air circulation in the presence of a horizontal temperature gradient.
51 (Nobre P., 2009a) Peer Review Question Interactive comment on "On the validity of representing hurricanes as Carnot heat engine".
52 (Gorshkov et al., 2000) Biotic Regulation of the Environment.
53 **Storm track map** showing all recorded paths of hurricanes; the equatorial regions containing forests and their oceanic surroundings are free of such storms: http://en.wikipedia.org/wiki/Storm_track Track, in English.
54 **Flood risk alleviation example**: http://www.forestry.gov.uk/fr/URGC-7QJDH7, in English.

2) Deforestation leads to an inhospitable climate

Bearing in mind the extensive, elaborate effects that forests have on climate as demonstrated by science, what can we expect from the devastation of these forests? To assess the impacts of deforestation on climate, a growing number of field experiments, modeling and observational studies, and, more recently, theoretical analyses have been made. What are the projected consequences of deforestation, and what has already been observed?

2.1) Virtual deforestation: simulating the annihilation of trees

One of the greatest virtues of climate models is their ability to simulate future scenarios. This type of exercise is not predictive in the physical sense; instead, it is the only tool for analyzing complex systems and making informed extrapolations in situations where the relevant physical theories are not yet available.

These simulations are valuable for specific situations, such as exploring climate risks associated with deforestation. In a virtual environment, such as a flight simulator, it is possible to repeatedly evaluate disaster scenarios, scrutinizing the decisive factors, the initial conditions and the potential consequences of risky maneuvers.

In 1991, Carlos Nobre led one of the most cited studies simulating the effects of total deforestation of the Amazon forest on climate[55]. Using a general circulation model (GCM[56]) of the atmosphere coupled with a vegetation module (SiB[57]), the authors found that when forests were entirely replaced by degraded pasture in the model, there was a significant increase in the average surface temperature (approximately 2.5°C) in conjunction with decreases in annual evapotranspiration (30% reduction), rainfall (25% reduction) and surface runoff (20% reduction). There was also an increase in the duration of the dry season in the southern half of the Amazon basin.

Over the next two decades, other studies provided additional details and more general results that supported these conclusions. Deborah Lawrence and Karen Vandecar recently conducted a literature review[58] on the impacts of tropical deforestation on climate, concluding that several GCMs agree that regional-scale deforestation would lead to a warmer, drier climate over the deforested area. The models that simulate complete deforestation of the Amazon predict a climate warming of 0.1-3.8°C (average of 1.9°C) and a rainfall reduction of around 140-640 mm per year (average of 324 mm/year, or a decrease of 10-15%).

However, deforestation can have much more serious implications. In 1997, German Poveda and Oscar Mesa[59] proposed the role of a hydrometeorological bridge for the Amazon rainforest, connecting the two

55 (Nobre C. et al., 1991) Amazonian Deforestation and Regional Climate Change.
56 Definition of GCM by Lawrence and Vandecar (2014): "... they are global, three-dimensional computer models of the climate system that operate on a large scale... The most recent include representations of the atmosphere, oceans, and land surface. [...] and an explicit representation of plant canopies and their effect on energy and water fluxes, including radiative and turbulent transfers, and the physical and biological controls of evapotranspiration."
57 (Sellers et al., 1986) Simple Biosphere Model.
58 (Lawrence and Vandecar, 2014) Effects of tropical deforestation on climate and agriculture.
59 (Poveda and Mesa, 1997) Feedbacks between hydrological processes in tropical South America and large-scale ocean-atmospheric phenomena.

great oceans, suggesting the existence of climatic cross effects between the two oceans, via the atmosphere, mediated by the rainforest.

Following in a similar direction, Paulo Nobre[60] et al. more recently studied the effects of deforestation on rainfall in the Amazon using numerical simulations that included or excluded the responses of the oceans to deforestation scenarios[61]. Comparing simulations performed with a typical atmospheric GCM and a GCM coupled to an ocean model that simulates the internal conditions of the oceans (e.g., salinity and currents), these authors found a significantly greater reduction in precipitation when the GCM coupled to the ocean model was run for a complete deforestation scenario in the Amazon; a 42% decrease in rainfall was projected when taking into account internal ocean mechanisms, compared to a 26% decrease in rainfall when these mechanisms were not represented in the model. The oceans have been there all along; including their internal responses allows for more realistic simulations.

Many of the model projections for the consequences of deforestation have already been observed, especially the expansion of the dry season. However, these virtual experiments indicated that a prolonged dry season would occur after the complete destruction of the Amazon forest but in fact it is already being observed after the clearcutting of just under 19% of the forest. Therefore, these models appear to underestimate the negative consequences of deforestation in simulated scenarios. The results of more recent projections that include ocean processes suggest even worse conditions and sound alarm bells.

The elimination of the forest – the main continental condensation agent – is equivalent to switching off the atmospheric moisture pump.

However, one must also consider the biotic pump theory and its predictions of reduced rainfall. Unlike conventional numerical models, a physical theory builds its blocks of knowledge based solely on the fundamental laws of nature. If the theory is correct, it makes it possible to quantitatively predict physical effects based only on an analysis of relevant scenarios and logic.

Makarieva and Gorshkov predicted that complete deforestation of the Amazon would reduce rainfall, primarily as a result of the dissipation of the low-pressure effect (suction) associated with condensation, which is linked to a decrease in surface evaporation. Because the biotic pump theory also accredits the availability of water vapor for rainfall in the Amazon to the ability of the forest to transpire, a total annihilation of the main transpiration agent could completely stop the biotic pump once and for all.

The theory suggests that when the pump that draws moist air to the continent is turned off, the moisture flow would change direction when condensation over the ocean became greater (whilst weaker than the biotic pump, the *oceanic* condensation *pump* is always turned

60 (Nobre P. et al., 2009b) Amazon Deforestation and Climate Change in a Coupled Model Simulation.
61 Using only the observed historical series of sea surface temperatures.
62 Already considering and excluding the effects of global circulation associated with inertial movements and accelerations.

on), which would lead to arid conditions on land[62].

The climate models used to simulate deforestation have not yet included this new physical theory, so they do not project this effect, which could result in a 100% decrease in rainfall.

2.2) Real deforestation: eagle eyes in space

Deforestation is both real and immense, and its effects on the climate are well documented. Studies using micrometeorological towers have shown that the replacement of forest by pasture leads to increased surface temperatures and decreased evapotranspiration, which is analogous to the model predictions[63]. Satellite observations have shown that during the dry season, in accordance with the biotic pump theory, evapotranspiration in forests has continued to occur or even increased, but that this is not the case in deforested areas[64].

Observations have shown that evapotranspiration of the forests continues to occur (or even increases) during the dry season, as predicted by the biotic pump theory; however, this is not observed in deforested areas.

Similar data have also indicated that forest transpiration is much greater than that determined by the models, which partially explains the underestimation, in large-scale models, of the reduction in rainfall caused by deforestation. Although some observational studies have shown an increase in localized rainfall with deforestation, more comprehensive studies, simulations with climate models and even theoretical analyses have clarified the local and transitory nature of this effect, which basically depends on the existence of forests surrounding deforested areas and the extension of these forests. The increase in rainfall becomes a decrease as soon as the surviving forested area crosses a certain threshold of distance from the cleared area. From then on, rainfall decreases.

Satellite data for rain and the presence of forest have shown a decrease in rainfall downwind of deforested areas.

Research by Spracklen et al.[65], using satellite data for rainfall and the presence of forest, showed that where deforestation has occurred, there is a decrease in rainfall in the downwind direction. In 60% of the tropics, air passing over dense forests produces at least twice as much rainfall as air passing over deforested areas. Although these authors have not yet considered the mechanisms and effects of the biotic pump theory, they have produced strong evidence that the negative impact of deforestation on climate is not only felt locally, but can also affect other regions both close by and afar.

Makarieva et al. placed the findings of Spracklen into perspective by applying the biotic pump concept and quantitatively explaining which physical factors are responsible for the reduction in rainfall downwind of deforested areas. They noted that this decrease in rainfall may be considerably greater than that indicated by Spracklen's group[66]. In the most deforested portion of the Amazon, there already is a progressive delay in the onset of the wet season, which has a profound effect on the agricultural sector.

For the most deforested portion of the Amazon, a progressive delay is already observed in the onset of the wet season, which has a profound effect on the agricultural sector.

Thus, in the discussion regarding deforestation, a question of doubt no longer lingers on its direct and indirect effects on the decrease in rainfall but rather moves onto the issue of the actual extent of deforestation. During 2011/2012, a "mere" 4,571 km^2 were deforested in the Brazilian Amazon. Compared with deforestation rates in peak years, such as 2004 (27,772 km^2), this seems to be a modest amount. Brazil deserves recognition for having achieved this reduction. The speed and efficiency with which Brazil achieved this decrease in the deforestation rate suggest that the strategy adopted should be applied to eliminate and reverse further deforestation in Brazil and worldwide.

Despite the encouraging news, this seemingly small deforestation rate would be sufficient to clear an area equivalent to the entire country of Costa Rica in a mere ten years. Furthermore, a reduction in annual deforestation rates attenuates the momentary perception of loss and masks the cumulative deforestation of the Amazon, which is exceedingly serious.

With regard to climate, what especially matters is the total area that has been deforested and its spatial distribution. Diógenes Alves[67] calculated total deforestation

63 For example: (Gash et al., 1996) Amazonian Deforestation and Climate; (von Randow et al., 2004) Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in southwest Amazonia.
64 (Huete et al., 2006) Amazon rainforests green-up with sunlight in dry season; (Saleska et al. 2007) Amazon forests green-up during 2005 drought.
65 (Spracklen et al., 2012) Observations of increased tropical rainfall preceded by air passage over forests.
66 (Makarieva et al., 2013) Why does air passage over forest yield more rain? Examining the coupling between rainfall, pressure and atmospheric moisture content.
67 (Alves 2007) Science and technology and sustainable development in Brazilian Amazon.

at 663 mil km² in 2004 based on a compilation of pioneering satellite investigations. By aggregating the latest figures from the PRODES project of the National Institute for Space Research (INPE), total cumulative deforestation reached 762,979 km² in 2013.

From a climate-damage perspective, what we have in Amazonia is a gigantic liability of destruction of the *green-ocean* rainforest. So there is no reason whatsoever to celebrate the relatively lower rates of clearcutting in recent years, especially since, after the adoption of the new Forest Code (2011) with its wide amnesty for those who deforested, a distinct tendency towards further increases in the annual rates has already been observed.

Going by INPE's calculations, the extent of clear-felled forest in Brazil (not taking into account other countries that form the Amazon basin) reached 18.85% of the original forest area in 2012[70]. However, destruction is not uniform because there is a high concentration of clearcutting in the so-called Arc of Fire (or Arc of Deforestation)[71]. If the vast expanse of forest that has been shaved totally bare is already extremely serious for the climate, the situation is even worse when we also consider the areas of rainforest that have been gravely-wounded.

Logging, gradual deforestation and fire produce extensive areas of degraded forests that are rarely included in official tallies of forest destruction but, from what we can infer from the information and estimates available, these areas can have a significant impact on climate.

Cumulative deforestation: 762.979 km²

The total deforested area is greater than the size of an area three times the State of São Paulo in Brazil, or the size of two Germanys or two Japans. An area unit easily grasped by Brazilians, the soccer field (4,136 m²), gives an idea of the magnitude of the devastation: 184 million soccer fields[68] - almost one soccer field deforested in the Amazon for every Brazilian. Placed in the context of time, the figures are staggering: 12,635 soccer fields deforested per day, 526 per hour, 8.8 fields or 36,291 m² per minute, or 605 m² per second without stopping over the last 40 years. To comprehend the enormity of these figures, you need to extend your imagination beyond these analogies. A fictional tractor that is operating a 3-m-wide front blade would need to accelerate to nearly the speed of a jet plane (726 km/h) to deforest the clearcut area in the Amazon at the pace recorded from space-borne imagery. Because a tractor deforests much more slowly (0.24 – 0.36 ha/h[69], or ~0.8 km/h, if the area is restricted to a 3-m wide strip), over 900 tractors with a 3-m blade would be required, side-by-side simultaneously cutting down the forest and forming a destructive front nearly 3-km wide. An even more striking comparison is that of a 2-km wide "deforestation road" which would cover the distance from the Earth to the Moon (380,000 km).

Dalton Valeriano led a pioneering study on land degradation[72] in the state of Mato Grosso from 2007 to 2010, and found "only" 7,856 km² of forest that had been clearcut but that there was a further 32,926 km² of degraded forest areas. If we add up the clearcut and degraded areas, very little is left of what originally gave the State of *Mato Grosso* (*Dense Forest* in Portuguese) its name.

During the same period, INPE mapped 64,205 km² of

68 Deforested area = 762,979 km² / 0.004136 km² = 184,472,679 soccer fields.
69 (Viana, 2012) Máquinas e Métodos de Desmatamento (Deforestation Machines and Methods).
70 **INPE deforestation monitoring database** interface: http://www.dpi.inpe.br/prodesdigital/prodesmunicipal.php. *Lista* (a table) and *Consolida* (sums for the considered area unit), in Portuguese.
71 Percentage of deforested area until 2012: state of Tocantins (TO) 75%, state of Maranhão (MA) 72%, state of Rondônia (RO) 41%, state of Mato Grosso (MT) 40%, state of Pará (PA) 22% and state of Acre (AC) 13%.
72 Prodes report 2008, pdf: http://www.obt.inpe.br/prodes/Relatorio_Prodes2008.pdf, in Portuguese.

degraded forest versus 39,026 km^2 of clearcut forest in the Brazilian Amazon. Using the relative proportion between these two distinct areas, the proportion of degraded forest can be extrapolated for the entire Brazilian Amazon. Based on this estimate, by 2013 the total degraded area may have hit the mark of 1,255,100 km^2. Added to the total measured clearcut area, the cumulative impact of human occupation on the biome may have reached 2,018,079 km^2.

Amongst the 200-plus countries in the world, only 13 of them cover an area greater than this. This estimate suggests that the degraded forest in the Brazilian Amazon may have reached as much as 29.44% of the original area[73]. When this is added to the clearcut area, it suggests that as much as 47.34% of the forest may have been directly impacted by climate-destabilizing human activities. For the Pan-Amazon region, this aggregated effect in the Brazilian Amazon represents from 26.68% to 29.03% of the original forest area when considering both deforestation and estimated degradation[74].

However, the affected area may be even greater from an ecological perspective because forests adjacent to degraded or clearcut areas suffer both directly and indirectly from the effects of environmental changes (both biogeophysical and biogeochemical) in neighboring areas[75].

In the degradation process, canopy destruction, which often exceeds 60% of the vegetation coverage[76], changes the structural, ecological and physiological characteristics of forests, compromising their environmental qualities and capabilities.

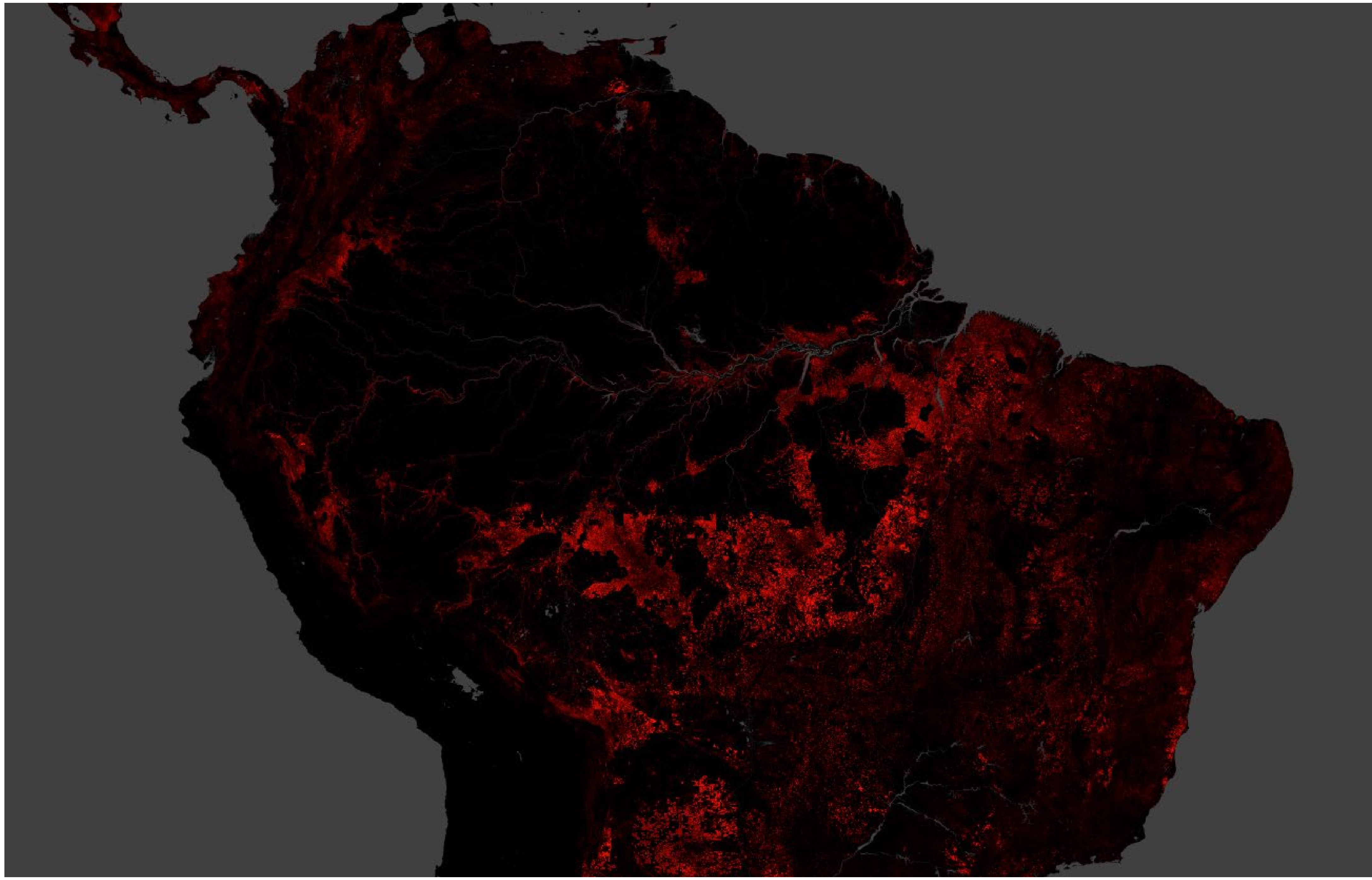


Figure 1 *Cumulative deforestation from 2000 to 2010 (lighter red) and prior to that period (darker red) in South America[77].*

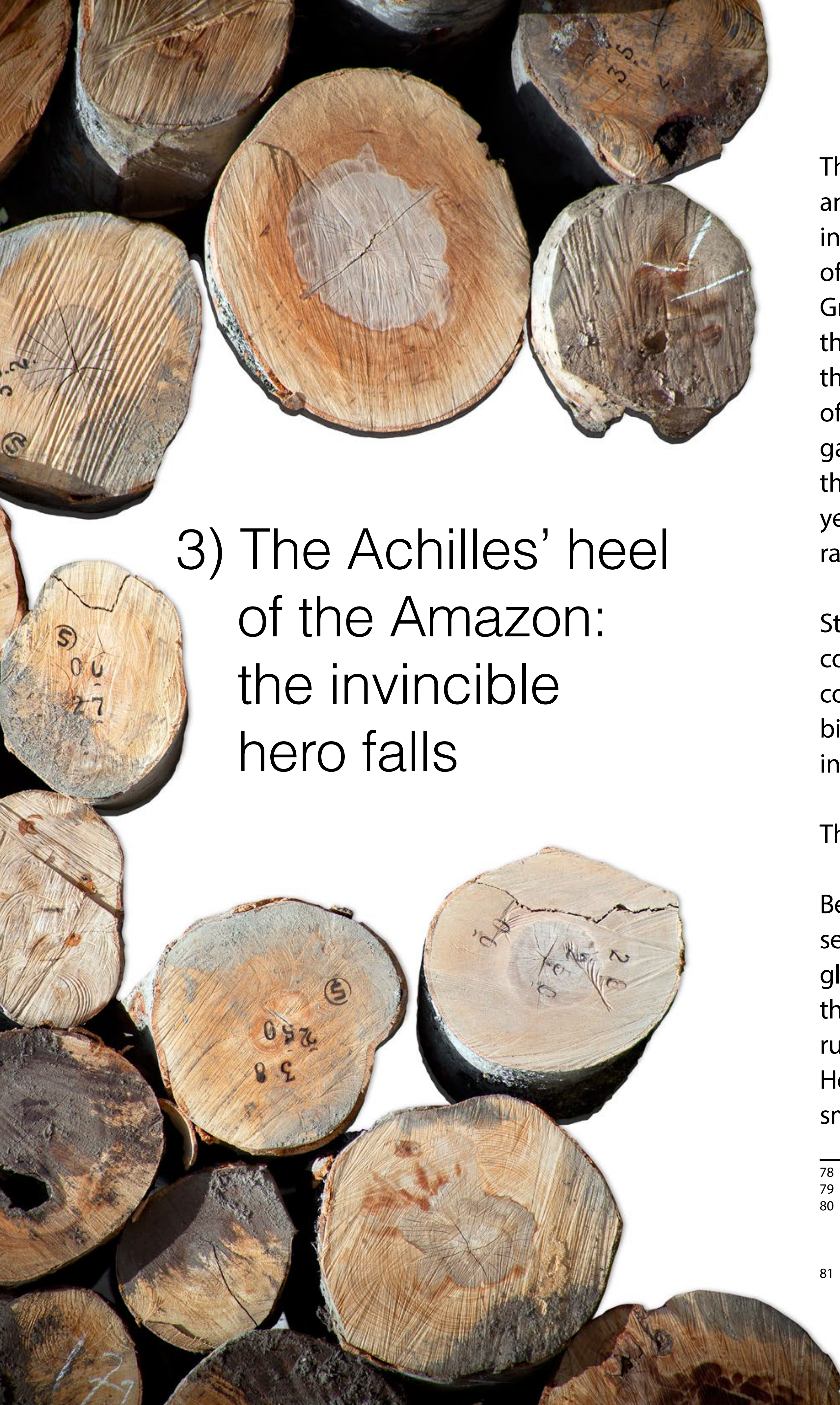
73 Calculation using the measurement from Espírito-Santo et al. (2014) for the remnant forest in the Brazilian Amazon [3,500,000 km^2] added to the area of cumulative deforestation [762,979 km^2], reaching 4,262,979 km^2 of original forest in the Brazilian Amazon.

74 Impact using the total area of original forest estimated by current coverage (remnant forests + cumulative deforestation) based respectively on Espírito-Santo et al. (2014) with 7,562,979 km^2 and Eva et al. (2005) with 6,943,468 km^2.

75 (Laurance & Williamson, 2001) Positive Feedbacks among Forest Fragmentation, Drought, and Climate Change in the Amazon.

76 (Valeriano et al., 2008) Monitoramento da Cobertura Florestal da Amazônia por Satélites. Sistemas **PRODES**: http://www.obt.inpe.br/prodes/index.php; **DETER**: http://www.obt.inpe.br/deter/; **DEGRAD**: http://www.obt.inpe.br/degrad/; e **QUEIMADAS**: http://www.inpe.br/queimadas/; 2007-2008 [Monitoring of the Forest Coverage of the Amazon by Satellite from 2007-2008 using the systems PRODES - Monitoring The Brazilian Amazon Rainforest by Satellite; DETER – Detection of Deforestation in Real Time; DEGRAD - Mapping Forest Degradation In The Brazilian Amazon; and QUEIMADAS - Monitoring of Fires In Near Real Time], all links in Portuguese.

77 **University of Maryland Global Forest Cover**: http://earthenginepartners.appspot.com/science-2013-global-forest, in English.



3) The Achilles' heel of the Amazon: the invincible hero falls

The forest has survived volcanism, glaciation, meteors and continental drift for over 50 million years. But now, in less than 50 years, it is under threat from the actions of mere human beings. There is a parallel between the Greek legend of Achilles' heel and the importance of the great Amazon forest for the Earth's climate. Like the Greek hero, the Amazon, which could be thought of as a massive assemblage of extraordinary living organisms, surely must possess some innate capability that made it an invincible warrior for tens of millions of years, surviving the geophysical cataclysms that have ravaged the planet from time to time.

Studies have revealed the great forest's ability to overcome the elements, from its humidifying atmospheric conditioning passing through cloud nucleation to its biotic pump, all suggesting elaborate mechanisms of invincibility. So where is the weak point in this system?

The answer is related to degradation and deforestation.

Because the great rainforest plays a key role providing services that benefit the stability of local, regional and global climates, its physical disruption means leading the "great warrior" to its defeat in these roles, like the rupturing of Achilles' tendon, making him lose the war. Here, the enemy's arrows are chainsaws, bulldozers, fire, smoke, soot and other factors related to human activities that have emerged from the wrongful, uncontrolled and terrible use of certain inventions in the Anthropocene[78], i.e., the new era in which humanity has become a geological force capable of changing the face of the planet.

3.1) Point of no return: the misstep into the abyss

If we imagine the metaphor of a vehicle (the great forest) traveling along a bumpy road (climate), with flexible tires that absorb and cushion the impact of the potholes (eco-climate resilience), how deep would the *climate hole* need to be to burst the tire of the *green-ocean* Amazon?

The intact green-ocean forest has many resources to absorb the effects of droughts and can completely regenerate itself over several years.

The effects of the most severe drought in a century were felt in 2005. Five years later, the effects of the 2010 drought were even greater and more extensive[79]. In 2010, cave paintings made during the glacial era thousands of years ago, when the sea level was 100m lower than it is today, were discovered on rocks at the bottom of the Negro river. The physical explanations for these two mega-events remain inconclusive; however, numerous observations[80], both from on land and from space, leave no doubt about the damage and losses endured by the forest[81]. These findings indicate that the Amazon *tire* is already showing signs of fatigue,

78 **Anthropocene, a planet transformed by humanity**: http://www.anthropocene.info/en/anthropocene , in English.
79 (Marengo et al., 2011) The drought of 2010 in the context of historical droughts in the Amazon region.
80 For example: (Brando et al., 2014) Abrupt increases in Amazonian tree mortality due to drought-fire interactions; (Saatchi et al., 2013) Persistent effects of a severe drought on Amazonian forest canopy; (Fu et al., 2013) Increased dry-season length over southern Amazonia in recent decades and its implication for future climate projection; (Marengo et al., 2013) Recent Extremes of Drought and Flooding in Amazonia: Vulnerabilities and Human Adaptation; (Phillips et al., 2009) Drought Sensitivity of the Amazon Rainforest; (Cox et al., 2008) Increasing risk of Amazonian drought due to decreasing aerosol pollution; (Hutyra et al., 2005) Climatic variability and vegetation vulnerability in Amazônia.
81 (Nepstad et al. 1999) Large-scale impoverishment of Amazonian forests by logging and fire. For example: extensive tree mortality, which significantly changes the vegetation structure and aborts the normal regeneration mechanisms in clearings.

or at least significant scars from the impacts it has suffered.

Under stable *green-ocean* conditions, the forest has a broad repertoire of ecophysiological responses to absorb the effects of such droughts[82], completely regenerating itself over the years. However, in extensive areas, especially along the Arc of Deforestation, one can already perceive the "multiple organ failure" of fragmented forest remnants and even of less fragmented areas[83].

Several harmful factors combine to the effect that droughts resulting from external pressure cause more damage than usual, reducing the forest's ability to regenerate itself. The first and foremost among such factors is deforestation itself. Without the trees, all the services that stretch of forest provided for the climate clearly disappear, and this in turn affects the remaining forest. Forest removal disrupts the biotic pump of atmospheric moisture, weakening its ability to import moist air to the region, generating rain. When the forest is removed by burning, smoke and soot cause a breakdown in the mechanisms of cloud nucleation and result in polluted and dissipative clouds that do not produce rain[84].

Deforestation disrupts the rain mechanisms. Without rain, the forest becomes flammable. Fire forms in the forest, burning surface roots and killing large trees.

The floor of a rainforest in pristine state is too damp to burn, even during the "dry" season. However, when no rainfall whatsoever falls in the dry season - something that did not use to happen but is now becoming increasingly common -, organic matter on the forest floor does dry to the point at which it becomes flammable. Fires penetrate the forest, burning surface roots and killing large trees[85]. All these deforestation side-effects are maximized and the armies of human enemies quickly strike the vulnerable warrior's heel. When will the forest fall forever? Several studies have suggested an answer: when it crosses the point of no return[86].

The point of no return is the beginning of a chain reaction, like a row of standing dominoes. When the first one falls, all the others will fall. Once brutally and irreparably unbalanced, the living system in the forest will ultimately leap over to another state of equilibrium.

3.2) Savannization and desertification: extensive or unthinkable damage?

With drought, fires and forest degradation, savanna is favored in a new climate equilibrium to the detriment of the forest.

Stable equilibrium is a state similar to that of a ball inside a bowl, which, under normal conditions, will always gravitate towards the deepest part of the container. With increasing oscillations of the bowl, the ball moves ever closer to the edges. When movements become vigorous enough to drive the ball right to the very edge, it will leave that first equilibrium-bowl behind and jump into another one.

82 (Phillips et al., 2010) Drought-mortality relationships for tropical forests.
83 (Laurance & Williamson, 2001) Positive Feedbacks among Forest Fragmentation, Drought, and Climate Change in the Amazon.
84 (Andreae et al., 2004) Smoking rain clouds over the Amazon.
85 (Nepstad et al., 2004) Amazon drought and its implications for forest flammability and tree growth: a basin-wide analysis.
86 For example: (Nobre and Borma, 2009) "Tipping points" for the Amazon forest.

In 2003, Marcos Oyama and Carlos Nobre hypothesized the savannization of the Amazon in their modeling study using a GCM and a vegetation equilibrium model[87]. Because climate interacts with vegetation, when one parameter is changed, the other tends to change via a positive (destabilizing) or negative (stabilizing) feedback until a new equilibrium is reached.

Climate and vegetation in the Amazon *green-ocean* are in stable and resilient equilibrium under wet conditions. With deforestation, the climate gradually changes and destabilizes until it reaches a point of no return (the edge of the wet bowl). The system may then take the jump to another state of equilibrium that is much drier.

According to this study, there are two possible equilibrium states for vegetation in the Amazon. One corresponds to the current distribution of vegetation, where the rainforest covers most of the basin, while the other is a state in which the rainforest in the eastern Amazon is replaced by savanna. With progressive drying, the introduction of fires and other large-scale alterations in the forest, savanna will be favored in the new climate equilibrium, to the detriment of the forest. In the second equilibrium state, even remnant areas of undisturbed forest will disappear, turning into savannas.

This hypothesis indicates that only protecting the forest that is still standing will not be sufficient to prevent its subsequent demise by virtue of climate change under the new equilibrium conditions. This perspective sheds new light on policies intended only to preserve the integrity of designated conservation areas.

These extrapolations generally consider scenarios with relatively modest decreases in rainfall and always assume that there will not be much change in wind direction when the forest is gone. In this scenario, the trade winds carrying moisture from the ocean would continue to bring it inland to the continent; only certain vertical exchanges over the Amazon would change.

However, the biotic pump theory, which explains how wind strength is related to condensation, predicts that a significant decrease in evaporation/condensation on land should lead to profound reduction of air convergence over the continent associated with a radical reduction of the net moisture transport or even its possible reversal. We might compare this land-sea relationship to a tug of war: the side where more atmospheric condensation occurs will win the contest and draw moisture toward itself. As it is the winds that bring moisture from the sea to the land due to the presence of the forest, without the forest, the atmospheric air could cease to converge over land, which could completely eradicate rainfall in the region. Zero rainfall would lead to the formation of a desert, not a savanna.

The savannization scenario projected by Oyama and Nobre's model (and later detailed further by other studies)[88] would be bad enough with its annihilation of the pure treasure of forest biodiversity. However, rain does fall in savanna country, so agriculture has some chance of continuing to be viable. But desertification resulting from progressive deforestation, as predicted by the biotic pump theory, would simply annihilate everything, including most human activities in the Amazon.

What about beyond the Amazon? Because most of the water that irrigates the bread-basket quadrangle of southern South America originates from the Amazon, the future climate of the continent may be considerably dryer. In a worst-case scenario, it would resemble present-day Australia: a vast desert interior fringed on one side by strips of wetter areas near the sea.

87 Using the same vegetation classes of SSiB. (Oyama and Nobre, 2003) A new climate-vegetation equilibrium state for Tropical South America.
88 For example: (Malhi et al., 2009) Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest.

4) The future climate of Amazonia: it has already arrived

Climate change in Amazonia and beyond has already begun. However, whether doomsday scenarios materialize or not, and how long it might take to reach such a low point, depend on many unforeseeable factors, including how much of the original vegetation cover will have been altered and at what rate.

With an acceleration of deforestation and a crossing of the point of no return - a moment which seems to be uncomfortably close -, only a few decades may be needed before the climate jumps to another equilibrium state[89].

If both deforestation is stopped and forest regeneration occurs, the immediate threat may be deferred to a more distant future. But this would all depend on the extent of remaining *green-ocean* rainforest and the magnitude of external climatic forces.

Human occupation of the Amazon has triggered an unthinkable contest, a race in which two nefarious influences – deforestation and global climate change – compete for first place on the podium for orchestrating the final destruction of the largest and most diverse rainforest on Earth[92].

The undisturbed rainforest has innate abilities to withstand external climate impacts, such as rainfall fluctuations. Over the last ten years, most climate models have attributed some measure of resistance by the forest to the effects of global warming. All the same, there is some uncertainty regarding the effective resistance of tropical rainforests to direct human activities, and this makes it difficult to project a set date for the complete and utter destruction of the forest based solely on model simulations.

> *The undisturbed green-ocean rainforest has innate capabilities to resist external climate impacts, such as rainfall fluctuations.*

Lack of rain: mortal threat to the Amazon

In 2000, Peter Cox et al. from the Hadley Centre published a startling article in *Nature*[90]. For the first time, the authors combined a general model of atmospheric circulation with an interactive vegetation model in which the carbon cycle was well detailed. Among the results, the model projected a sharp, progressive and permanent decrease of rainfall in the Amazon, which would lead to its gradual death. With the forest drying up, fire would easily penetrate and large amounts of carbon would be released, resulting in a sharp worsening of global warming. For the first time, a climate model had predicted a terrible fate for the great rainforest. Fourteen years hence, the new Hadley Centre model is similar to the others. It no longer suppresses the forest due to external effects[91] as it did before. Nevertheless, the effects of the original Hadley Centre model affected the forest through decreased rainfall, as a direct consequence of excessive CO_2 in the atmosphere and the resulting warming. However, errors in rainfall prediction may occur in climate models. It is precisely the reduced rainfall levels that are the greatest threat to the forest. If these models do not correctly predict the decrease in rainfall, they will not place the forest in danger. Because none of the current climate models incorporate the mechanisms and effects predicted by the biotic pump theory of atmospheric moisture, especially regarding the potential effects of the changes in wind circulation (suppressed large-scale convergence over dry land), their projections may be uncertain. We may come to discover in the future that the original model from the Hadley Centre was the only one to predict the future climate of Amazonia, although possibly not for the correct reasons.

89 (Coe et al., 2013) Deforestation and climate feedbacks threaten the ecological integrity of south-southeastern Amazonia.
90 (Cox et al., 2000) Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model.
91 (Good et al., 2013) Comparing Tropical Forest Projections from Two Generations of Hadley Centre Earth System Models, HadGEM2-ES and HadCM3LC.
92 (Malhi et al, 2008) Climate change, deforestation, and the fate of the Amazon.

Roughly speaking, and without considering the debilitating effects of forest degradation, one can crudely extrapolate the known history of clearcutting - ~20% of the forest cover of the Brazilian Amazon removed over the past 40 years, already with marked effects on the climate – and project a further 40 years for the removal of an additional 20%, we thus arrive at a total of 40% of accumulated clearcutting of the forest, precisely the threshold suggested by climate models[93]. However, the effects of deforestation compound the impact of fire, forest degradation and climate change, leading to an acceleration of the expected scenario.

Despite the fact that climate models are useful, well-founded extrapolations, past climates may not offer a firm basis for predicting the future, especially when addressing complex systems and when the climate equilibrium is near the "edge of the bowl", ready to jump over to another equilibrium state. We will only know for certain when the future arrives, but it would be irresponsible for us to simply sit still and wait.

Anthropogenic disturbances, although already extensive and most likely excessive, represent the most unpredictable factors for projecting the final fate of the Amazon. The simple reason is that we humans have free will. If we choose to carry on with *"business as usual"*, and especially if we opt not to repair the damage inflicted upon the great forest, theory suggests that the whole Amazon system may collapse in less than 40 years. Deforestation thresholds at which climate models suggest a breakdown of the current climate system are rapidly approaching. Local- and regional-scale climate effects are being observed much earlier than expected, especially in the most devastated areas, but also in more remote areas that relied on the forest for rainfall[94].

The future climate of Amazonia has already arrived. It is our responsibility to put scientific knowledge to good use.

Thus, based on observed changes, the future climate of Amazonia has already arrived. The urgent and already tardy decision to take and amplify immediate actions cannot wait, if there actually is a chance of reversing the threatening situation. Investments in scientific research focusing on the Amazon have yielded rich, substantiated and readily available information. It is our responsibility to put this knowledge to good use.

4.1) Climate reciprocity: cumulative deforestation demands immediate payment

The limitless deforestation spree is finding that the climate is a judge who very well knows how to count trees and who neither forgets nor forgives.

With a significant decrease in historic annual deforestation rates, Brazil has emerged as an example of a country that has done part of its homework regarding climate change. For a nation that has spent 40 years investing heavily in environmental missteps and violating its own forest protection laws, a reduction in deforestation is no mean feat. However, the drop in annual deforestation rates, while essential, is akin to using one's hands to block a

93 (Sampaio et al., 2007) Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion.
94 (Sampaio et al., 2007).

hole at the bottom of an inflatable boat (climate) once the water that has leaked in over the last 40 years (deforestation) is already threatening to sink it. The limitless deforestation spree is finding that the climate is a judge who very well knows how to count trees and who neither forgets nor forgives.

Future deforestation, or how much of the remaining forest we can cut down, is the typical focus of discussions on the future climate of Amazonia. Unjustifiably absent from such discussions, the nightmarish proportions of cumulative deforestation of the past need to come back into the limelight because the main aspects of climate reciprocity are directly related to these past activities. Without addressing past devastation, the nightmares will return to haunt us.

Producing a daily average of approximately 4 mm of transpired water[98], which is equivalent to 4 liters/m^2, the rainforest is a generous donor to favorable climate. Once the forest is replaced with pastures, transpiration plummets to 1 mm (if it rains at all)[99], or even less when aridification occurs.

When we add fire, smoke and soot - with their annihilating effects on the forest, clouds and rain -, to the boiling cauldron of inequities, the curse of an inhospitable climate will be Nature's fair response to so much destruction. The problem is that the "punishment" affects everyone indiscriminately, not only those who deforested and encouraged deforestation but also the great majority of people who were and still are against it.

Tree guillotine

It is estimated that the Amazon biome used to house 400 or more billion trees with a diameter of more than 10 cm at breast height[95]. Calculating the distribution of a population of trees on an area basis, it can be inferred that clearcutting deforestation has destroyed over 42 billion trees in Brazil alone, in the last 40 years[96]. Lined up, the trunks of these trees -with an average height of 15 m-, would cover 635 million km, or nearly 1,700 times the distance between the Earth and the Moon. This destruction rate means (on average) that more than 1 billion trees are cut down every year; that is nearly 3 million per day, more than 120,000 per hour, over 2,000 per minute or 34 per second[97]! These figures do not include the potentially greater number of trees cut down in so-called degraded forests. In the last four decades, nearly 6 trees in the Brazilian Amazon were destroyed for every person on Earth, over 200 for every Brazilian. The climate notices these trees are gone because each decimated tree represents, among the many severed services, less surface evaporation.

4.2) Order of urgency: better late than never

So that we can contemplate the true dimension of what needs to be done regarding the future climate of Amazonia (and consequently of South America), let us imagine a scene in the future in which Brazil might be attacked by a powerful enemy nation possessing secret

95 Average population of trees (DAP > 10cm) in Amazonia (*sensu latissimo* Eva et al, 2005, A proposal for defining the geographical Boundaries of Amazônia) = 555 (±114) /ha, that is, 55.500 (±11.400) trees/ km^2 (Feldpausch et al., 2011, Height-diameter allometry of tropical forest trees); total area covered by closed canopy in Amazonia by 2004 = 6.280.468 km^2 (Eva et al, 2005 including wet, dry and flooded forests); historic area covered with forest (forest area in 2004 plus clear cut deforestation by 2004, Alves 2007) = 6.943.468 km^2 (may be higher if you include deforestation accumulated outside of Brazil); Total estimated minimum of trees in the original Amazonian biome: 385.362.474.000 (±79.155.535.200).

96 Clearcutting shaved 762.979 km^2 of the original cover (in Brazil only); estimated trees removed with clearcutting = 42.345.334.500 (±8.697.960.600).

97 Temporal rhythm of cutting: 42.345.334.500 (±8.697.960.600) trees cut in 40 years; 1.058.633.363 (±217.449.015) trees per year; 2.900.365 (±595.750) trees per day; 120.848 (±24.823) trees per hour; 2.014 (±413) trees per minute; 33,5 (±6,9) trees per second.

98 (von Randow et al., 2013) Inter-annual variability of carbon and water fluxes in Amazonian forest, Cerrado and pasture sites, as simulated by terrestrial biosphere models. (Marengo, 2004) Characteristics and spatiotemporal variability of the Amazon River Basin Water Budget.

99 (Hodnett et al., 1996) Comparisons of long-term soil water storage behavior under pasture and forest in three areas of Amazonia.

technology that uses disruptive waves emitted by satellites to dissipate clouds and thereby reduce rainfall. Let's say the enemy nation has commercial interests that are threatened by the success of Brazil's agricultural sector. A rain-killing weapon could be used to stunt crops that compete with theirs, destroying harvests in Brazil and causing international prices to skyrocket. If the Brazilian secret service informed Brazilian farmers about the misdeeds of that said country against them, what would their reaction be? What would society's reaction be? And the government's? With all the humiliation apportioned by such an outrage, we hardly need to be a clairvoyant to imagine that the reaction would be immediate and powerful.

Not only does the removal of forests defeat agriculture, but the lack (or excess) of water also affects energy production, industry and city life.

Leaving the realms of fiction behind and returning to reality, we see that the very same outrage is already being perpetrated against Brazil now, at this very moment, without the involvement of any foreign nation. In an undeclared war that has been going on over the last 40 years, hundreds of thousands of people have dedicated themselves to exterminating the forests.

The removal of the rainforests, threatening both rainfall and climate, will not only damage competitive agriculture, but a lack (or excess) of water will also affect energy production, industry, urban water supplies and life in the cities in general. However, unlike Europe and the United States during World War II, we have been and continue to be virtually inert in the face of these attacks on the forest, allowing them to continue year after year and destroy our *splendid cradle*[100]. Who are these people who pose such a threat to Brazil's well-being? Why has society not risen up? Why has the Brazilian Army not been mobilized in the nation's defense?

To address the gravity of the situation we are in, we need to mount a campaign similar to a war effort, although not one directed toward conflict. The first urgent line of attack needs to be a "war" against ignorance, an unprecedented effort to enlighten society in general, but including especially those who still cling to the mistaken belief that the devastation of the forests is harmless. The perpetrators are not only those who wield chainsaws or incendiary devices, or those who tear down the forest with anchor chains hauled by tractors, but just as much the groups who draw up public policies and who finance, control and give legislative, legal and propaganda cover to the devastation *commandos*. However, only a small part of society was and still is directly involved in the destruction of the forests. It is this minority that pushes the nation toward the climate abyss.

This deforesting minority is not uniform, but their culture favors interests that are entrenched in a short-term view, regardless of the consequences. Driven by immediate, narrow interests, they seem to ignore the fact that the removal of forests can put climate at risk.

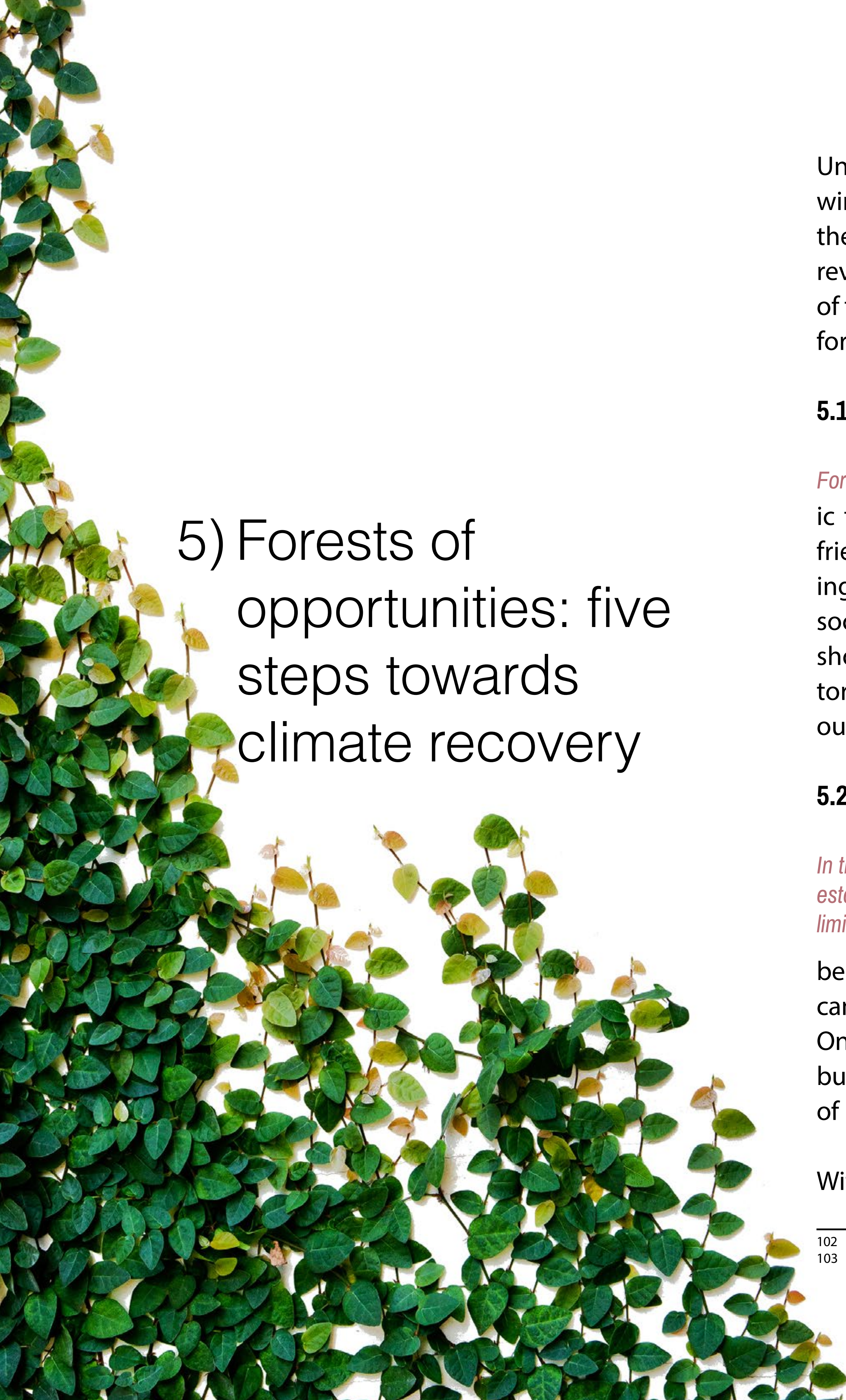
War effort

When major threats to a nation arise, the armed forces are immediately put on stand-by. After the Japanese attack on Pearl Harbor, the United States decided it was necessary to join World War II. In a few months, it mounted a "war effort". Car manufacturers started to produce tanks and warplanes, while other non-combat factories began producing ammunition, weapons and other materiel and equipment that was required. This war effort even reached the Amazon, with its rubber soldiers. Without such a concentrated and extraordinary effort, the allies would not have won.

To continue with this practice, given the available evidence, is simply not justifiable. Therefore, as they begin to understand that the systematic destruction of the forest is a shot in the foot, there is a chance that these agents of deforestation could be convinced to change. The perspectives and hopes are that the eradication of ignorance regarding the essential role of forests in generating a favorable climate will in itself be a move towards converting those who deforest into protectors, perhaps – who knows – even into forest restorers. Many examples of conversions like this already exist, with great advantage to all involved[101].

100 N. of T. *"Deitado eternamente em berço esplendido"* [Laying down ethernally in *splendid cradle*] is a verse of the Brazilian national anthem.

101 In projects like **Lucas do Rio Verde Legal**: http://www.tnc.org.br/tnc-no-mundo/americas/brasil/projetos/lucas-do-rio-verde.xml; Paragominas: De vilões a mocinhos do desmatamento [**from villain to good boy of deforestation**]: http://www.tnc.org.br/nossas-historias/destaques/paragominas-deixa-lista-do-desmatamento.xml; **Y Ikatu Xingu**: http://www.yikatuxingu.org.br/; etc. All links in Portuguese.



5) Forests of opportunities: five steps towards climate recovery

Until we reach the point of no return, there are a few windows of opportunity for restorative action. Now is the time to engage forcefully in a healing war-effort to reverse climate disaster resulting from the destruction of the Amazon *green-ocean*. Several tasks must be performed to this end.

5.1) Popularize forest science: knowledge is power

Forest: he who knows it, protects it. It is vital that the scientific facts regarding the role of the forest in creating a friendly climate and the effect of deforestation in leading to an inhospitable climate should reach all levels of society and become common knowledge. Every effort should be made to simplify the message without distorting its very essence. One should, above all, reach out and appeal to people's sensibilities.

5.2) Zero deforestation: start yesterday

In the short term, zero deforestation is essential if we wish to limit further damage to climate.

Complacency and procrastination concerning all this destruction must be utterly eradicated. An adequate level of stringency can be compared with the treatment given to tobacco. Once the harm smoking does to people and economic burdens it inflicts on society were ascertained, a series of measures were adopted to discourage it.

With regard to deforestation in Brazil, several steps have been taken by the federal government to initiate processes of control and dissuasion. Significant results have been achieved. However, we need to dig much deeper and get to the real root of the problem by expanding executive policies and mobilizing society to counteract disruptive actions taken by the legislative branch, such as granting amnesty to those who deforest as per the new Brazilian Forest Code. Unfortunately, discussions surrounding the new Forest Code did not include repercussions of land use on the climate.

An exceptional situation requires exceptional measures. It is always the right time to revise laws and adapt them to the demands of reality and of society. Giving fines to deforesters who later on will simply be amnestied through bureaucratic inefficiency or by Congress is a recipe for failure.

Other vulnerabilities of the deforestation control program include the stimulating effects of economic cycles[102], growing market demands for timber and agricultural products, a greed for land and vectors represented by roads, dams and other development programs, with planning weaknesses that foster the invasion and occupation of forested areas[103]. For deforestation to be stopped effectively, which is essential if we wish to limit further damage to climate, all these loopholes must be sealed with the mobilization of and articulation by society and the government, using strategy, intelligence, a long-term vision and a sense of urgency.

102 Land-clearance can be stimulated by changes in national economic policies. Deforestation peaks in 1995 (29,059 km^2) and 2004 (27,130 km^2) for example, occurred at the height of an economic boom.
103 (Laurance et al., 2001)The Future of the Brazilian Amazon.

5.3) Put an end to fires, smoke and soot: call the fire department!

The fewer sources there are of smoke and soot, the less damage will be done to clouds and rain and, in turn, the less damage to the green-ocean rainforest.

All forms of ignition originating from human activities in the forest must be halted once and for all. Fires in forest areas, pastures and on agricultural land are a serious problem, regardless of their proximity to the Amazon[104]. The fewer sources there are of smoke and soot, the less damage will be done to the formation of clouds and rain and, in turn, this will result in less damage to the *green-ocean* rainforest. Given the deeply ingrained habit of using fire as an agricultural tool in the countryside, this will be no easy task but it is an essential one.

Let us go back to the comparison with tobacco. For decades, the industry covered up the facts on the health risks posed by smoking. Elaborate strategies and many resources in cognitive scrambling were used in attempts to discredit science and confuse society. However, the truth ultimately prevailed. Something that had seemed impossible became an irreversible global trend. The same path could be taken by putting a total ban on setting fires. Many alternatives to burning already exist and can be used by producers to their advantage.

5.4) Recover deforestation liability: the phoenix rises from the ashes

Although the reforestation effort is challenging, it is the best (and perhaps only) way to divert a greater risk to the climate.

Although stopping deforestation is mandatory, inescapable and long overdue, it alone is not sufficient to reverse threatening climate trends. We must confront the liability of cumulative deforestation, beginning with paying the principal on the enormous environmental debt that we owe the forest.

How can a devastated landscape be rebuilt? If it were an urban landscape, the answer would be to rework structures and buildings, in laborious brick by brick reconstructions that would require years of effort. By contrast, Nature's inert structures, such as soils, rocks and mountains, took thousands, millions or even billions of years to form and are the fruit of the actions of slow geophysical forces.

From a climate perspective, we must regenerate all that has been destroyed.

What about the living landscape? If earlier life has not been made extinct, i.e., if there are propagules, spores, seeds, eggs, parents and their offspring, a mysterious and automatic reconstruction force goes into action. The biological "bricks" are the atoms, which bond into molecules and compose the substances that build cells, articulate themselves into the tissues, agglomerate into organs, form organisms, populate ecosystems, interact in biomes and whose sum total is the biosphere.

For a practical idea of what is implied in this interlinked and automatic living order, imagine what it would be like if we had modern assets (human technology) at the tip of our fingers in the same way that nature does. We could order a car (species) that would come in a ready-to-develop module (seed). When placed in a pot in the sunlight and watered for a few weeks, the vehicle would grow!

Does that sound difficult? Well, it turns out that such technology already exists, and has been operating at full steam in Earth's ecosystems all along. A magnificent tree - with a physical and biochemical ability simply to exist and survive that borders on fiction - started off from a simple, tiny seed, drawing all it needed to form itself from the air and the soil.

Thus, the forest itself offers us outstanding solutions for ways to reconstruct native forest landscapes because it possesses ingenious mechanisms to rebuild (or heal) itself from mere seeds via the natural process of tree regeneration in natural gaps.. There is a wealth of pioneer plant species that have the ability to grow under extreme environmental conditions. These plants establish a dense secondary forest, creating conditions for the complex, lasting tropical forest to recompose itself gradually by medium- and long-term restoration[105].

104 (Koren et al., 2004) Measurement of the Effect of Amazon Smoke on Inhibition of Cloud Formation.
105 (Nobre, 2006) Fênix Amazônico, Renascendo das Cinzas da Destruição (Amazonian Phoenix, rising from the ashes of destruction). Proposal to build an ecosystem of sustainable enterprises in the Amazon.

However, when a deforested area is very large, natural regeneration processes fail because pioneer seeds do not reach the bare soil. In such cases, it becomes necessary to plant native species. If rain still falls, the forest regenerates in replanted areas. A collection of planted trees is better than bare ground, but it is still a long way from rebuilding the functional part of the destroyed ecosystem in all its complexity[106].

The landscape must be used in an intelligent manner by zoning the land according to its capabilities, vulnerabilities and risks.

We must regenerate, as widely as possible, all that has been changed and destroyed. It was only the integrity of the original *green-ocean* forest that secured the benign health of South America's water cycle, sustaining it throughout geological eras.

Reforestation on such a scale implies a reversal of land use in vast areas that are now occupied, something that is highly unlikely under the current scenario. Nevertheless, there are alternative paths with a good chance of immediate acceptance. It is a matter of making intelligent use of the landscape, including the application of land zoning technologies based on terrain potential, vulnerabilities and risks[107].

Agriculture and other economic activities in rural areas can be optimized by increasing production capacity and freeing up space for reforestation with native species. Many studies by Embrapa[108] have shown how to intensify livestock production, greatly reducing the demand for pasture area. Projects such as Y Ikatu Xingu[109] and Cultivando Água Boa [Cultivating Good Water][110] have shown how an association of stakeholders from different sectors is perfectly workable in the recovery of riparian forests and other valuable sustainability actions.

The predicted climate chaos has the potential to be immeasurably more damaging than World War II. What is unthinkable today may become an unavoidable reality sooner than expected. China, with all its serious environmental problems, has already understood this and become the country with the most on-going reforestation activities. Restoring native forests is the best bet we can make against climate chaos and is the only true insurance policy we can buy.

5.5) Governments and society need to wake up: reality shock

In fifteen days, at a cost of trillions of dollars, governments of several nations decided to save the banks in the financial crisis of 2008.

In 2008, when the Wall Street financial bubble burst, governments around the world took just fifteen days to decide to use trillions of dollars of public funds to save private banks and avoid what threatened to become a collapse of the financial system. The climate crisis has the potential to be immeasurably worse than any financial crisis, nonetheless the

106 Partners: People and reforestation in the Tropics: a network of education, research and synthesis: http://partners-rcn.uconn.edu/page.php?4, WeForest: http://www.weforest.org/, both in English. .
107 This could be achieved by applying the **terrain model HAND**, which was developed in the Terrain Modeling group of the Earth System Science Center at INPE: http://modelohand.blogspot.com.br/, in Portuguese.
108 Brazilian Corporation of Agricultural Research, https://www.embrapa.br/en/meio-ambiente, in English.
109 **Y Ikatu Xingu, save the good water of Xingu**, http://www.yikatuxingu.org.br/, in Portuguese.
110 **Cultivating Good Water**, a program from Itaipu Binational (hydroelectric company) http://www.cultivandoaguaboa.com.br/, in Portuguese.

Despite being urgent, zero deforestation seems to remain a goal to be achieved in the distant future.

ruling elite has been procrastinating for over fifteen years on making effective decisions to save humanity from climate disaster. Despite the abundance of scientific evidence[111] and of viable, creative and appealing solutions[112], this procrastination seems to be worsening.

In the Amazon, delays in decision-taking are directly related to lengthy deadlines for goals and actions that should be considered urgent but get bogged-down in impenetrable, impeditive bureaucracy. Delays are also related to sluggishness in providing funding for alternative, beneficial projects, and especially with regard to the slow appropriation of scientific facts about the importance of forests for climate. Ignoring innovative, affordable and feasible solutions for increasing the economic value of forests[113] is simply postponing the problem. Zero deforestation, which was already a matter of urgency a decade ago, is still presented as a goal to be met some time in the distant future. All this is in stark contrast to the fifteen days needed to save the banks.

We saw the first coherent and consequential efforts to effectively reduce deforestation in the Brazilian Amazon gain momentum starting in 2004. The results are plain to see, showing that it is indeed possible to go even further. However, despite auspicious initiatives and important promises in carbon projects, we are still light years away from the "war effort" that is needed to address climate degradation. To move forward with any effectiveness at all, further creative, forceful initiatives are urgently needed.

The ruling elite can still change the course of events. They must have the willingness and humility to recognize the imminent risk of collapse in the environmental system.

Amply documented by science, global climate change and threatening regional- and local-scale impacts from deforestation keep a foot in the door of political lethargy, putting increasing pressure on decision makers. If qualified scientific knowledge, the precautionary principle and even plain common sense have failed to spark an adequate reaction from those who have the financial means and strategic resources to change things, then the shock of dry taps here, flooded cities there and other natural disasters must surely provoke some sort of reaction.

111 (Edenhofer et al., 2014) IPCC WGIII AR5 SPM : Summary for Policymakers; (Agrawala et al., 2014) IPCC WGIII AR5 TS Technical Summary.
112 For example: (Stern, 2007) Stern Review on the Economics of Climate Change; (Sukhdev, et al., 2009) **TEEB** - The Economics of Ecosystems & Biodiversity: Climate Issues Update: http://www.teebweb.org/, in English.
113 For example: (Meir et al., 2011) Ecosystem Services for Poverty Alleviation in Amazonia; (Trivedi et al., 2009) REDD and PINC: A new policy framework to fund tropical forests as global 'eco-utilities'.

Conclusions

In the great Amazon rainforest, Earth safeguards one of its most spectacular treasures: a profusion of life-forms that inhale carbon dioxide and exhale oxygen, transpire water, emit magical odors, remove toxic gases, pulsate and regulate, moisten and make it rain, propel winds and feed aerial rivers, appeasing the fury of the elements, creating an amenable climate both nearby and afar. Societies sheltered beneath its life-giving breath find in it an umbilical cord that sustains their economies and provides them with well-being. All this makes it necessary, desirable, viable and even profitable to change the *modus operandi* of human occupation in the Amazon.

There are many alternatives for reviving the respectful coexistence with the rainforest, characteristic of ancient civilizations.

Although the proposed relief operations are all necessary if we are to achieve the functional rehabilitation of climate regulation by the forest, the novelty lies in facing off deforestation liabilities through reforestation and ecological restoration. Many excellent alternatives exist for reviving the respectful (and technological) coexistence[114] that ancient civilizations once enjoyed with the forest[115].

The war effort against ignorance and for an awareness of the vital importance of forests is the best strategy of bringing people together – starting with our leaders – around the common goal of making up for lost time and creating real opportunities for us to avoid the worst of all climate disasters. However, if we still fail to act despite the mountain of scientific evidence, or if we are just too slow to make a move, then it is highly likely that we will have to deal with losses incomprehensible to those who have always taken for granted the shade and fresh water we enjoy thanks to the generosity of the great rainforest.

114 (Balée, 2003) Native Views of the Environment in Amazonia.
115 (Heckenberger et al., 2003) Amazonia 1492: pristine forest or cultural parkland?

Epilogue: the prologue of a new era

The mythical Amazon rainforest is immensely greater than whatever humanity manages to see in it. It is more than just a geographical museum of endangered species held in conservation areas and it is certainly much much more than a simple carbon deposit referred to somewhat disparagingly as a "dead mass" in climate treaties.

The forest is a spectacular technological park of nature, a living complex, a powerful, versatile factory of environmental services. Any call made for the valuation of the forest must embrace this intrinsic value. We need to invoke our capacity to be awed at the gigantism of tropical biology on all scales, from the manipulation of tiny atoms and molecules to the interference of oceans and the global atmosphere.

What we see of human interference with the Amazon rainforest reveals a substantial lack of awareness, both from those involved in its destruction and from those who vaguely seek its protection. Each new initiative intended to defend the forest has walked the same paths and pressed the same keys. By following this pattern, we insist on what Einstein defined as insanity itself: "Doing the same thing over and over again and expecting different results."

Abundant scientific knowledge and other accessible forms of perception and understanding already enable us to solve problems using a new approach – one that is enlightened, integrative, proactive and constructive. An approach, moreover, that differs from the reductionist, irresponsible pragmatism that brought us here in the first place[116].

Comprehensive, serious analyses afford numerous opportunities for harmonizing the presence and interests of contemporary society with an Amazonia that is alive and vigorous and can be rebuilt to its full capability. To get there, we need enthusiasm, modesty, dedication and a commitment to life. With the technological resources available, we can "occupy" in an intelligent way, optimizing new forms of land use that leave room for the ecological rehabilitation of the forest. We can also disclose many other well-kept secrets of resilient tropical biology and thus go beyond a mere understanding of its mechanisms.

A pioneer in perceiving these opportunities, Janine Benyus, in her book *Biomimicry, innovation inspired by Nature*[117], started a revolution with the notion of a connection between nature and technology. Introducing the proposition that human beings should consciously copy the genius of Nature in their own creations, she sets out three basic principles for this rapprochement:

· *Nature as a model:* to study and be inspired by Nature's systems, designs and processes in order to solve human problems.

· *Nature as a measure:* to use standard or ecological criteria to judge the correctness of our innovations. After evolving for 3.8 billion years, Nature has learned what works, what is appropriate and what lasts.

· *Nature as a mentor:* a new way of looking at and appreciating Nature, from which a new era might arise based not on what we can "extract" from the natural world, but on what we can learn from it.

In addition to these three points, several other principles that guide the workings of Nature could potentially solve most of the current problems. A short list of these principles outlined by Janine Benyus notes that Nature is propelled by sunlight; it uses only the energy it needs; it fits form to function; it recycles everything; it rewards cooperation; it banks on diversity; it demands local expertise; it curbs excesses from within and it taps the power of limits.

116 As seen by Einstein: "We cannot solve problems by using the same kind of thinking we used to create them." Pragmatism, the generator of problems, should not be the solution to solving the same problems.
117 (Benyus, 1997) Biomimicry: Innovation Inspired by Nature.

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