Restore Ecosystems to Cool the Climate

Peter Bunyard and Rob de Laet

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Abstract

A healthy rainforest acts as a critical component of a heat pump, whereby the sensible heat at the Earth's surface is transported as latent heat upward through the air column and, following water vapor condensation, is released once more, as sensible heat, into space. The cooling engendered by evapotranspiration and subsequent cloud-forming is two orders of magnitude greater per surface area than the cooling brought about by carbon sequestration in forming biomass. Over rainforests far from the coastal source of humidity, rainfall and latent heat release on cloud-forming remain as high, if not higher, than at the coast. For this

P. Bunyard (✉)
Independent Researcher, Ecorestoration Alliance, Fellow Linnean Society, Bodmin, UK
e-mail: peter.bunyard@btinternet.com

R. de Laet
Ecorestoration Alliance, Global Evergreening Alliance, Amsterdam, Holland

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phenomenon of enhanced precipitation, the authors refer to the biotic pump principle in which the implosive, abrupt force of partial pressure reduction, consequent to water vapor condensation, causes the sharp upward flow of air in the air column such as to draw in the humid air of the same latitude ocean. Based on evapotranspiration data and average rainfall over the Amazon Basin, the authors determine that regeneration of tropical rainforests over an area of 2.5 million square kilometers would be the most effective means to combat global warming and would be sufficient for now to stop the planet from heating up further, while the world is decarbonizing the global economy. To be successful, such regeneration would necessitate primarily the restoration of coastal rainforests in order to activate the biotic pump.

Keywords

Latent heat · Biotic pump · Heat pump · Gaia · Hydrological cycle · Hadley cell · Climate · Global warming · Angiosperm evolution · Evapotranspiration

Introduction

The year 2023 has proved to be the hottest on record, adding to a succession of record-breaking years since the beginning of the twenty-first century. And, with those records, we have come to expect extreme weather events, ranging from life-threatening heat waves, devastating storms, unprecedented droughts like that afflicting the Amazon Basin, rainstorms and floods that have not been experienced before, severe forest fires, and increasing crop failures. The rate of global warming and the environmental devastation in its wake have taken climatologists by surprise. In effect, the global mean temperature at 1.43 °C above the 1850–1900 pre-industrial average for 2023 has proved to be the highest on record, being 0.10 °C higher than the 10-month average for 2016, previously the warmest calendar year. The global temperature increase is getting uncomfortably close to the 1.5 °C limit above pre-industrial levels at which point, according to the Intergovernmental Panel on Climate Change (IPCC), we will be at a threshold, beyond which it may prove next-to-impossible to return to cooler temperatures.

On May 9, 2024, *The Guardian* newspaper published the results of a survey it had carried out in which it stated the following: "Hundreds of the world's leading climate scientists expect global temperatures to rise to at least 2.5 °C (4.5 °F) above pre-industrial levels this century, blasting past internationally agreed targets and causing catastrophic consequences for humanity and the planet" and "Almost 80% of the respondents, all from the authoritative Intergovernmental Panel on Climate Change (IPCC), foresee at least 2.5 °C of global heating, while almost half anticipate at least 3 °C (5.4 °F). Only 6% thought the internationally agreed 1.5 °C (2.7 °F) limit would be met" (https://www.theguardian.com/environment/article/2024/may/08/world-scientists-climate-failure-survey-global-temperature).

Despite the Paris COP 21 agreement of 2016 to reduce greenhouse gas emissions from fossil fuels to zero by 2050, in 2023, the quantity emitted worldwide actually rose by 1.1% from the previous year to 36.8 billion metric tons of CO_2. When land-use emissions are included, global CO_2 emissions in 2023 are set to total 40.9 billion tons. According to the NASA, the extra warming since pre-industrial times, measured as 1.81 W/m^2, is equivalent to 0.75% of the solar energy received on average at the Earth's surface.

In its annual Emissions Gap Report, the United Nations stresses that, even if current pledges to reduce CO_2 emissions were met, temperatures are likely to rise above 2.5 °C from pre-industrial levels and therefore at least 1 °C above the 1.5 °C maximum rise called for. The prospect of such a large temperature rise is highly disturbing. The climate consequences, whether from heat waves, droughts, or floods, will not only hurt food production but lead to migrations on a massive scale and far greater than the world has currently experienced. Is there nothing to be done but hope that global anthropogenic greenhouse gas emissions will be cut back by nearly 9% per year for the next decade? The trend is in the opposite direction and, for example, in 2023, the United Kingdom government, which had been at the forefront for reducing emissions from greenhouse gases and for strategies to prevent further global warming, offered more than 100 new offshore licenses for petroleum and natural gas exploration off the Scottish coast in the North Sea, while putting back the commitment to ban the sales of new petrol- and diesel-powered cars and vans from the original deadline of 2030 to 2035. At the COP 28 meeting in Dubai in 2023, agreement was finally reached that all countries should phase out the use of fossil fuels by 2050, yet the timing of how and when was left in the hands of individual countries. The likelihood of meeting the 1.5 °C target is becoming vanishingly small.

If we are to cool the planet, the focus on reducing greenhouse gas emissions is needed but far from sufficient. That focus, indeed an obsessive one, is based on the notion, strongly evident in past IPCC Assessment Reports, that fossil fuel burning is the primary cause of global warming and that land-use change and damage to ecosystems are a secondary matter, particularly in terms of greenhouse gas emissions, such as when forests are cleared and burnt, all the while losing their capacity to take up CO_2 and generate biomass. What has been missing from past Assessment Reports is a proper accounting of the role played by the biosphere and its biodiversity-rich ecosystems in generating climate. So far, the IPCC reports neglect that the atmosphere has, to a large extent, been created by the biosphere, indeed by life itself, over a period of hundreds of millions of years. The current benign climatic conditions within which we, as a species, have been nurtured since neolithic times has been the result of a set of complex positive and negative feedbacks, seemingly carefully designed by ecosystems to optimize surface conditions, including temperature, for the biosphere, ourselves included. The hydrological cycle, especially as influenced by living processes such as forest evapotranspiration and the emission of cloud-enhancing aerosols, is a critical factor in terms of energy flows and heat transfer. If we are to cool the climate and mitigate the accelerating extreme weather events, we believe a first and crucial step is to recover ecosystems, including rainforests, which have been degraded and destroyed over the past 100 years. In fact, an area the size of China or the USA has been cleared of forest since 1850, the start of the reference period for global warming used by the IPCC.

Such action to restore destroyed ecosystems would be a win-win situation, first by allowing a beneficial hydrological cycle to re-establish itself and second, by enabling biomass growth and the accompanying take-up of atmospheric CO_2.

Lovelock's Gaia Hypothesis

James Lovelock, who died on his 103rd birthday, 26 July 2022, was a trail-blazing scientist who changed our thinking on the relationship between life in its broadest sense, as the sum of the biota, and its environment. Lovelock accepted the Darwinian "survival of the fittest" as an explanation for the evolution of species, but with a telling difference, namely, that life in all its forms so modified its immediate environment that the transformations it engendered to the Earth's physical/chemical surface, including the crust, oceans, and atmosphere, optimized the environmental conditions for survival for a host of different species, from bacteria to the tallest sequoia. Such life-caused changes to the environment then fed back on the process of evolution in a tight co-evolving and coupled relationship. The biosphere, therefore, stretched, as far as Lovelock was concerned, all the way from the Earth's crust to the outer edges of the atmosphere (Lovelock 2000).

Lovelock's *Gaia Hypothesis*, now more than 50 years since it was first formulated, has therefore provided us with a fundamentally new way of looking at life on Earth and, in particular, that the Earth's surface and climate were, in large measure, the result of surface phenomena becoming transformed as a consequence of life's metabolic activities. James Lovelock made us realize that climate and the changes it has undergone over aeons of time, are a consequence of the biota's interaction with the atmosphere, such as to modify the impact of physical events, be they changes to the Sun's luminosity, volcanic eruptions, or simply cyclical changes to the Earth's orbit, as in Milankovitch's wobbles (Lovelock 2000; Bunyard 2022; Hitchcock and Lovelock 1967).

Lovelock realized, when working in the 1960s for NASA's life-seeking Viking Missions to Mars, that the hand of life was to be seen in the Earth's atmosphere. In sharp contrast to the CO_2-dominated atmosphere of Mars, Lovelock and Margulis pointed out that the Earth's atmospheric concentrations of the constituent gases, in particular nitrogen, oxygen, carbon dioxide, nitrous oxide, and methane, were all a consequence of biotic metabolism, especially of bacteria, whether free-living, like cyanobacteria and certain species of azotobacter, or whether in endosymbiotic relationships, as is the case of rhizobacteria found in the root nodules of legumes, mitochondria, and chloroplasts, all of which inhabit eukaryotic multi-celled organisms and bring about nitrogen fixation, photosynthesis, and respiration. The extraordinary relationship of oxidizing and reducing gases present at the same time in the Earth's atmosphere, despite constant redox interactions, was the clue that living processes, as they evolved, transformed their immediate environment, all the way from the Earth's crust to the outer atmosphere. Lovelock liked to portray the Earth as a geo-physiological system or superorganism, with different ecosystems playing the role of the Earth's organs.

As Lovelock and Margulis proclaimed in 1974: "Furthermore, any planetary biota which interacts with its atmosphere will drive that atmosphere to a state of disequilibrium which, if recognized, would also constitute direct evidence of life, provided the extent of the disequilibrium is significantly greater than abiological processes would permit. It is shown that the existence of life on Earth can be inferred from knowledge of the major and trace components of the atmosphere, even in the absence of any knowledge of the nature or extent of the dominant life forms." And they continued: "On Earth, the simultaneous presence of O_2, and CH_4, at the present concentrations is a violation of the rules of equilibrium chemistry of no less than 30 orders of magnitude. Indeed so great is the disequilibrium among the gases of the Earth's atmosphere that it tends towards a combustible mixture, whereas the gases of Mars and Venus are close to chemical equilibrium and are more like combustion products."

Finally: "During the time, 3.2×10^9 years, that life has been present on Earth, the physical and chemical conditions of most of the planetary surface have never varied from those most favourable for life. The geological record reads that liquid water was always present and that the pH was never far from neutral. During this same period, however, the Earth's radiation environment underwent large changes. As the sun moved along the course set by the main sequence of stars its output will have increased at least 30% and possibly 100%. It may also have fluctuated in brightness over periods of a few million years. At the same time hydrogen was escaping to space from the Earth and so causing progressive changes in the chemical environment. This in turn through atmospheric compositional changes could have affected the Earth's radiation balance. It may have been that these physical and chemical changes always by blind chance followed the path whose bounds are the conditions favouring the continued existence of life. This paper offers an alternative explanation that, early after life began, it acquired control of the planetary environment and that this homeostasis by and for the biosphere has persisted ever since" (Lovelock and Margulis 1974; Lovelock 2000).

As environmental conditions change from the impact of external physical forces and from the biota's metabolic activities, living organisms evolve to meet those changes. That process fits in well with the 1972 punctuated equilibrium theory of Niles Eldredge and Stephen Jay Gould in which the evolution of species undergoes long periods of stasis, followed by rapid, punctuated evolution in response to a sharp, dramatic change to environmental conditions (Eldredge and Gould 1972).

The impact of plant evolution on the hydrological cycle has been particularly marked, not just enabling the Earth to retain its surface water but also, through photosynthesis, providing free oxygen in the atmosphere and, by means of the physics of evaporation and condensation, bringing about a significant cooling of the atmosphere as solar energy is transported in the form of latent heat from a vegetated surface to the outer atmosphere and from there to Space. For all that, the cooling of the Earth's surface through the biotically manipulated hydrological cycle has not been properly considered in IPCC's Assessment Reports or in any of the COP meetings and resolutions, including those of COP 28.

The Atmosphere: Emergent Property of the Biota

The atmosphere regulates the energy that comes in from our Sun, that immensely powerful star which, by transforming hydrogen into helium, gives us the fusion radiation energy that fuels life processes on Earth. Much of that radiation is lethal to life, and we have to thank the stratosphere for giving us a protective layer against the Sun's detrimental ultraviolet radiation. The oxygen, provided by life through photosynthesis, percolates into the stratosphere and interacts with ultraviolet C, the most powerful in the spectrum of UVs, thereby preventing the UV-C from radiating down to the surface, where it would kill life such as ourselves. Meanwhile, ozone, resulting from the interaction of UV-C with oxygen, does its bit of interacting with UV-B, thereby lessening the amount of such radiation that can penetrate to the surface. Hence our concern about the "ozone hole" (Fig. 1).

Indeed, we learnt about the ozone hole because of Lovelock's discovery that the chlorofluorocarbons were permeating the atmosphere from one Pole to the other. In 1957, Lovelock invented the Electron Capture Detector (ECD), a clever tool for measuring trace contaminants such as the chlorofluorocarbons which, as refrigerants and propellants for aerosol sprays, were beginning to become widely used in the industrialized world. The device used a radioactive isotope of nickel to provide

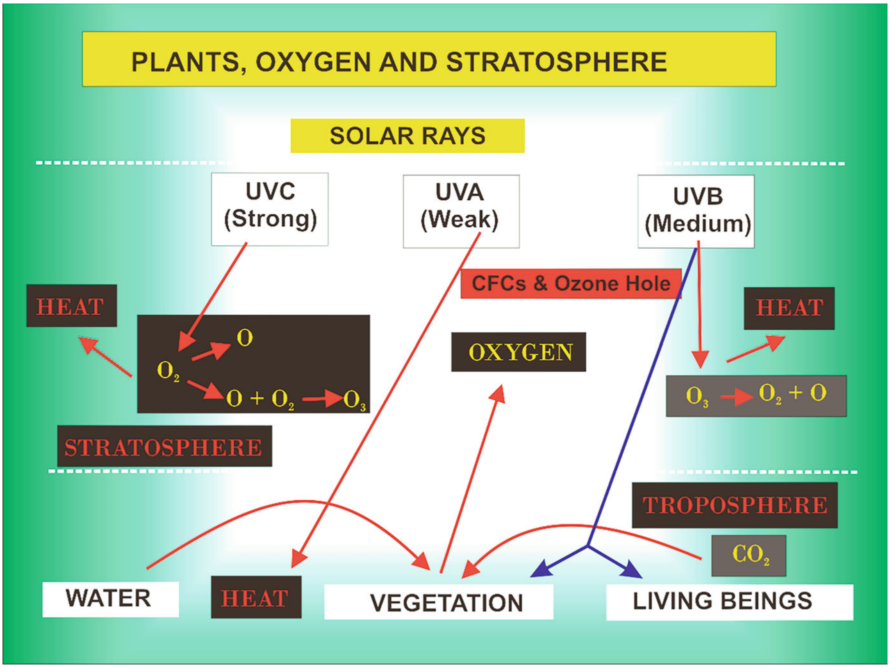

Fig. 1 Schematic overview of the interaction between sunlight, the atmosphere, and the biosphere. Oxygen generated by plants protects life on the surface from harmful ultraviolet Sun rays. (Peter Bunyard 2024)

electrons as beta radiation which then interacted with nitrogen gas to generate a measurable current. The nitrogen acted as a carrier gas for the sample which, by means of the attached gas chromatograph, contained the separated traces of the volatile substance to be measured, in particular halogenated compounds such as the CFCs. The presence of such substances resulted in the absorption of electrons, thus reducing the flow of electrons and the current. The ECD, now widely used, is extraordinarily sensitive and can measure the quantities of a volatile substance even to as low as one part per trillion.

In 1971, Lovelock was in the South Atlantic on board the research vessel, RRS Shackleton, with his ECD and a home-made gas chromatograph and to his astonishment he found traces of the CFCs which had permeated there from the industrial North. That discovery then led to concern that the CFCs, by percolating upward into the stratosphere, were responsible for the chemical/photolytic destruction of the ozone cap which, when properly intact, interacted with ultraviolet B radiation and thereby acted as a shield in preventing harmful UV-B radiation from reaching the Earth's surface.

Based on Lovelock's discovery of the prevalence of CFCs in the lower atmosphere, in 1974, Mario Molina and Sherwood Rowland expressed their concern on scientific grounds that the CFCs were damaging the stratospheric ozone cap, and 10 years later the United Nations, under what was termed the Montreal Protocol, introduced a ban on the use of CFCs. In 1995, Rowland, Molina, and the atmospheric chemist, Paul Crutzen, received the Nobel Prize in Chemistry. Lovelock's crucial contribution was ignored (Molina and Rowland 1974).

In addition, the ionosphere, a layer of the atmosphere populated with charged particles, interacts with the magnetic field and solar wind and aids in the deflection of these potentially harmful particles. Without such mechanisms in place, and the protective effects of the Earth's magnetic field, these harmful rays could dramatically affect living organisms and certainly would not allow for such abundance of life including ourselves. Apart from all this, the atmosphere forms an effective barrier against incoming space debris, such as small meteors, which, upon entry into the Earth's atmosphere, burn up because of their high velocities and the friction generated as they pass through the air. The outcome of this process, visible as shooting stars, protects the Earth's surface from continuous impact. That said, the atmosphere does not protect against the rare event of being struck by very large meteors. The last mass extinction on Earth was caused by the impact of a large meteor, the size of Mt Everest, which famously led to the extinction of large dinosaurs some 66 million years ago during the Cretaceous period. The event happened near the current town of Chicxulub in the Yucatan Peninsula, Mexico. It had a devastating impact the world over.

The Angiosperm Revolution

With respect to the potential cooling of the Earth's surface by means of latent heat transfer through the atmosphere, a fundamental change took place 100 million years ago with the evolution of broad-leafed angiosperm (flower carrying) rainforest species. As C. K. Boyce and his colleagues from the Missouri Botanical Garden note: "Transpiration capacity is closely correlated with leaf vein density and the average leaf vein density of angiosperm leaves is four times greater than that of all other plants, living or extinct. A rapid transition to high vein densities occurred separately in three or more flowering plant lineages about 100 million years ago. Climate modelling of the impact of this physiological revolution indicates that the tropics would be hotter, drier and more seasonal in the absence of angiosperms and the overall area of tropical rainforest would decline substantially. Because angiosperm diversity is influenced by rainforest area and by precipitation abundance and evenness the high diversity of angiosperms is partially a product of a positive feedback loop with the climate modifications initiated by the angiosperms themselves. Lineage diversifications among vertebrate and invertebrate animals and non-angiosperm plants may be tied to the unprecedented impact of angiosperms on climate" (Boyce et al. 2010; Benton et al. 2022).

One hundred million years ago, the average surface temperature at the Earth's surface was 7 °C higher than at the beginning of the industrial revolution, 250 years ago, and carbon dioxide levels were close to 3000 ppm by volume compared with 280 ppm by volume at the turn of the nineteenth century. The spread of angiosperm forests across the continents, as they then were, would help explain the extraordinary decline in atmospheric CO_2 and the reduction in temperature.

However, whereas the temperature decline is more or less linear over the past 100 million years, the CO_2 decline appears to be exponential with a leveling off 20 million years ago. As discussed below, forests contribute to global cooling by using evapotranspired vapor to carry latent heat from the surface and upward in the atmosphere toward outer Space. If indeed forests cool the surface by both mechanisms, carbon uptake into biomass and latent heat export, the rapid decline in CO_2 would be accounted for by the spread of angiosperm forest ecosystems across the continental landmass and the temperature reduction by both mechanisms operating simultaneously.

As an allegory of life cooling the Earth's surface by means of its color, in 1983, Andrew Watson and James Lovelock developed their *Daisyworld*, in which two distinct populations of black and white daisies competed against each other, while over aeons of time the Sun-like main sequence star increased its luminosity. At the beginning, when the Sun was relatively less luminous, the Daisyworld's surface temperature was close to freezing and neither of the two species of daisies could grow and expand their populations. As time passed and the star's radiation to the planetary surface increased, it became warm enough for the daisies to germinate and grow. Nevertheless, with the temperatures still low and just above freezing, the black daisies, by absorbing the incoming energy through their low albedo, could warm their local environment and, in so doing, gain a competitive advantage over the white daisies with their reflective, cooling high albedo. Biologically speaking, the optimum temperature for growth and development is in the region of 22 °C, and, as the black daisies covered a larger and larger area, the surface temperature became propitious for the white daisies, with the two species together maintaining an environmental temperature which stayed close to the optimum. Meanwhile, as time passed, the star's luminosity increased, and the black daisies, by overheating their local environment, lost their competitive advantages to the while daisies. At a certain moment in time, even the white daisies could not reflect sufficient of the star's rays and abruptly the planet became lifeless (Watson and Lovelock 1983).

On the basis that a surface temperature of 22 °C is the optimum for mainstream life, we should take into account that the tropical humid rainforests, circumscribing the equatorial region of our planet, have surface temperatures not far removed from the optimum. That beneficial surface temperature is the result of the relatively high rate of evapotranspiration (1.37 m annually) and the cooling engendered by the absorption of sensible energy in the form of latent heat. Yet, 100 million years ago, when the angiosperm tropical trees first evolved, the surface temperature over the equator would have been considerably higher, given that the mean surface temperature was at least 7 °C warmer than 200 years ago (Figs. 2 and 3).

Could it be that, like the white daisies cooling the surface temperature of Daisyworld, the added rate of evapotranspiration engendered by the angiosperms with their veined leaves would have given such species the competitive advantage because of the added cooling through latent heat transport from the surface to Space? Furthermore, could it be that the very success of the tropical forest species of angiosperms in cooling the equatorial surface would have resulted in the polar regions becoming sufficiently cold for permanent ice caps to form, taking the Earth's Milankovitch wobbles into account as the planet orbited the Sun? In effect, the cooling of surface temperature to beneficial levels because of the evolution of angiosperm forest species may be a clear example of Lovelock's *Gaia in Action*.

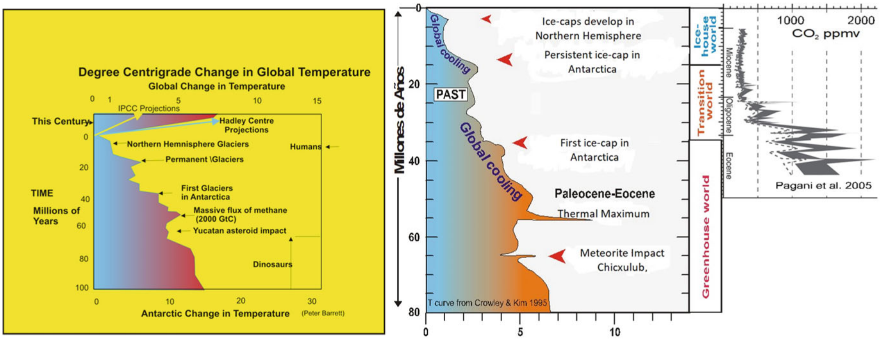

Fig. 2 Cooling over the past 100 million years largely follows a linear path, whereas the reduction in atmospheric CO_2 is logarithmic with a leveling off 20 million years ago when the average global temperature was still 2 °C above pre-industrial levels. (Diagrams from Peter Barrett 1999, ©Peter Bunyard) (Pagani 2005)

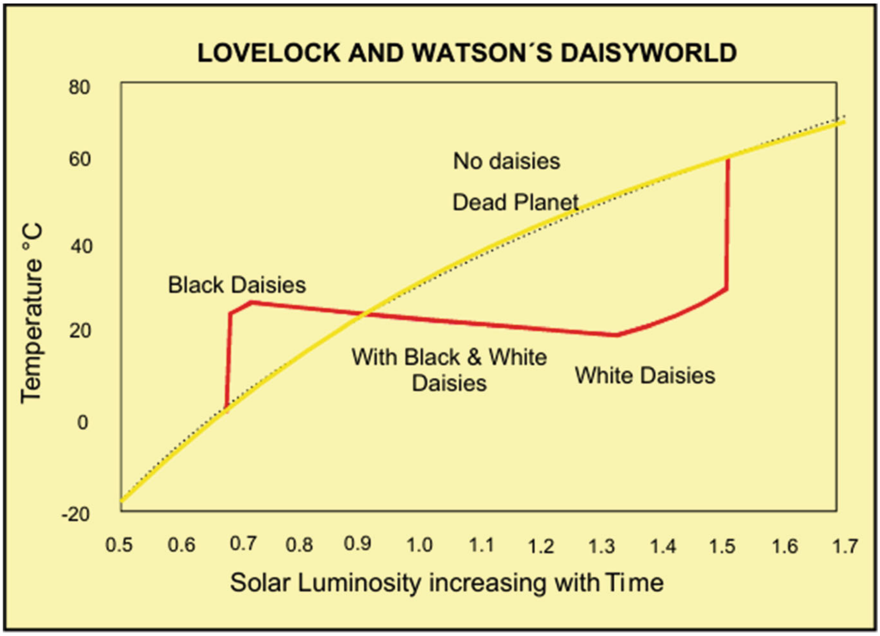

Fig. 3 Watson's and Lovelock's Daisyworld, showing how optimum temperature regulation is achieved by the albedo-mix of the daisies against increasing luminosity. The red curve represents both types of daisies, the yellow dotted curve is the temperature trajectory on a lifeless planet (Watson 1996)

Rainfall Recycling

From studying the proportion of deuterium and oxygen-18 isotopes in rainwater carried by the airflows from the tropical Atlantic Ocean to the western reaches of the Amazon Basin, some 3000 km inland, Eneas Salati and his colleagues determined that the rain was recycled at least five times across the expanse of the Amazon Basin, the distance from evaporation to precipitation covering on average some 600 km. Salati, as has been confirmed since, also found that as much as 60% of rainfall was re-evaporated by forest transpiration and that such evapotranspiration contributed to the watering of the rainforests further to the West (Salati 1987).

The average rainfall over the forests of the Amazon Basin amounts to 2250 mm per year. The average evapotranspiration over the Basin amounts to 1370 mm per year, hence 61% of the rainfall, thus confirming Salati's finding of 40 years ago. For each square meter, the energy absorbed per second, as latent heat, amounts on average to 98 W, given that the annual evapotranspiration amounts to 1.37 mt of water per square meter, with each gram needing 2257.2 J to bring about the phase change from liquid to vapor. The solar input on average per second to the surface amounts to 240 W/m^2. Therefore, the latent heat absorbs more than 40% of the total irradiation received at the surface. When we add in the extra 40% of evaporated moisture to make up the average rainfall, then the total latent heat required amounts to 161 W/s, with the smaller portion being derived from solar evaporation which has taken place over the tropical Atlantic Ocean.

On forming rainfall clouds over the Amazon Basin, the vapor condenses and releases all the latent heat as infrared radiation. As much as 50% will immediately irradiate upward to Space. As McIlveen (p. 443) points out, thermodynamically, it is relatively straightforward to calculate the temperature increase in each kilogram of air as condensation takes place, $\Delta T = L\ m/C_p$, where T is the Kelvin; L is the latent heat of vaporization of water vapor directly to ice, 2.9 MJ kg^{-1}; m is the mass in g; and C_p is the heat capacity of dry air at constant pressure, 1000 J kg^{-1} K^{-1}. McIlveen gives the example of 1 g of water vapor condensing into liquid water and shows that it will warm 1 kg of air by 2.5 °C: a substantial amount (McIlveen 2010).

The warmed-up, relatively dry air will rise and, in cooling as it expands, will release energy into its immediate surroundings, some of which will, like before, escape to Space. Meanwhile, the warmed-up air gets carried by the high-level jet stream toward Africa, all the while cooling further and releasing its energy, such that over time, a considerable proportion, if not all, of the original latent heat will have escaped to Space.

The temperature change from the partial pressure implosion, when 1 g of water vapor condenses, leads to 1 kg of air cooling by 0.17 °C. Again physics provides the answer according to the formula: J or Ws $= \frac{\Delta Pa}{\Delta t}$ $m^3 = 1000\Delta T_v$ where $\Delta T_v = 0.621\ \Delta q\ \ T$, q being the specific humidity of the air parcel in kilograms of water vapor for each kilogram of moist air, T being the air temperature, with q being derived from the equation $q = 0.621\frac{p_{wv}}{p_{atmos}}$ where p_{wv} is the partial pressure of water vapor and p_{atmos} is atmospheric pressure.

Multiplying the small temperature reduction, ΔT_v by C_p, the heat capacity of dry air at constant pressure, 1000 J kg^{-1} K^{-1}, the negative kinetic energy in Joules or watt.seconds can be calculated. As shown in the above calculation, the change in T_v relates to the net negative kinetic energy derived from the rate of change in the partial pressure of water vapor (*ppwv*) and the subsequent expansion of the surrounding air (from below) to fill the partial vacuum. For the condensation of 1 g of water vapor in 1 kg of air at 0 °C, the temperature reduction would be 0.17 °C (McIlveen 2010).

Given that the temperature change when the latent heat is released from 1 g of water vapor leads to 1 kg of air warming by 2.5 °C, the energy of latent heat is therefore approximately 2.5/0.17 or 15 times greater than the implosion energy of condensation. Nevertheless, the two are wholly different phenomena, one being mechanical and the other electromagnetic, and the temptation to subtract the 0.17 °C from the 2.5 °C must be resisted; otherwise, the implosion energy will be ignored and not taken into account when considering the validity of the biotic pump (McIlveen 2010).

The energies involved in condensation-implosion are considerable. Over the Brazilian Amazon (5.2 million square kilometers), they amount to 66 W/m^2 if delivered over 4 h in the mid to late afternoon. That is sufficient energy to cause an air current of 11.5 m/s, strong enough to account for the Trade Winds. Indeed, the implosion energy from cloud-forming over the 7 million square kilometers of the Amazon Basin is equivalent to the energy of one 18.6 kt atomic bomb going off every second (McIlveen 2010; Bunyard et al. 2019, 2024).

The high rate of evapotranspiration from the rainforest leads to dense cumulus-nimbus clouds, which form mostly in the mid to late afternoon. Such clouds have a relatively high albedo and reflect a considerable proportion of the incoming sunlight back out to Space. If such clouds were to reflect up to three-quarters of the incoming sunlight back to Space during the time of their formation and dissipation, some 4 h from midday to late afternoon, that would add an average cooling effect of some 30 W/m^2 and would amount to an average 12.5% cooling of the total surface sunlight received during 24 h. The forming of clouds over the tropical rainforest, plus the export of latent heat energy from water vapor condensation, could result in as much as 80% of the total daily solar input to the Earth's surface being returned to Space, hence close to some 200 W/m^2 of the average 240 W/m^2 received from the Sun (Fig. 4).

An annual rainfall of 2.25 m is equivalent to 2.25 million grams of water per square meter and the latent heat in joules for that quantity amounts to 580 kWh throughout the year per square meter of forest. At one-fifteenth the energy of latent heat, the implosion energy per square meter amounts to 40 kWh (McIlveen 2010).

With an average annual rainfall over the Amazon Basin of 2.25 m, per day on average, precipitation will deliver 6.165 kg of water per square meter. If we assume that such delivery takes place over 4 h during cloud formation, then per second the delivery amounts to 0.43 g of rainfall which generates an implosion energy of 66 J/s/m^2

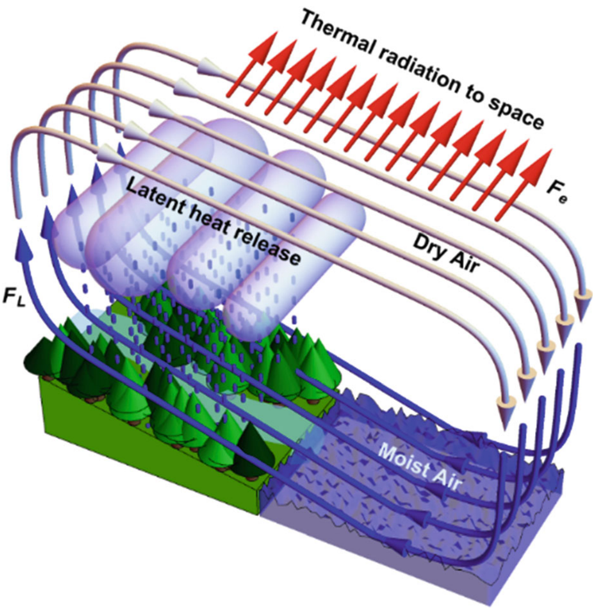

Fig. 4 Diagrammatic representation of the Hadley Cell circulation indicating the onshore flow of surface air (biotic pump) and the formation of clouds with latent heat irradiation release to Space. (©Anastassia Makarieva) (Bunyard 2024)

and a reduction in atmospheric pressure of 0.66 hPa/s/m^3, as water vapor condenses into clouds. That significant pressure reduction will immediately cause the air from below to flow upward to fill the partial vacuum at a rate approaching 10 m/s. The newly arrived air will feed the process and, again, condensation will take place. That process will continue during rainfall and, importantly, will draw in the surface humid air from the tropical Atlantic Ocean.

The cooling brought about by the transport of latent heat to the point of condensation and release of that latent heat energy, in the form of sensible, heat affects the amount of time the energy of the Sun remains at the surface. In Southern Spain, at the height of summer, the daytime temperature may reach close to 50 °C. That unbearable high temperature is a consequence of the solar energy remaining at the surface for an extended period, lasting even through the night. Meanwhile, the forest of the Amazon Basin, by means of its high rate of evapotranspiration, will have significantly cut short the time that the sensible heat of the Sun remains at the surface. In a nutshell, how much of the solar input of energy remains over 24 h at any point on the Earth's surface is a matter of the length of time that it takes for the energy to dissipate to Space. With an upward flux of air attaining a velocity of up to 7 m/s, during cloud-forming over the rainforest, in approximately 2 min, the surface air will have reached an altitude of 1 km and in half-an-hour an altitude of 10 km. In effect, two processes are involved in the surface cooling: the first, evapotranspiration and the absorption of latent heat; and the second, the ascending, upward flow of air, caused primarily by the abrupt pressure change as clouds form from the same evapotranspired water. The net result is that over the 24-h of each day, the rainforest keeps the surface temperature close to 25 °C.

With the Sun, moving as it were from East to West over the rainforest, the process of cooling, combined with the pressure change, will act like a rippling wave and in the case of the Amazon Basin, will help to drive the humid equatorial Walker Circulation to the rainforests of the far West.

In their study of the carbon uptake of a recovering degraded forest in the Amazon, Viola Heinrich and her colleagues found that as much as 75 t of carbon per hectare accumulated during the first 5 years of the regrowth. That added carbon amounts to some 1.5 kg/m^2 per year. Across the three main tropical rainforest regions of the world, including Central and South America, Africa, and Indonesia, Heinrich estimates that 60 million hectares are undergoing a process of recovery, therefore some 1.5% of the world's forested area. These recovering forests play an outsized role in carbon sequestration, absorbing 5% of all carbon taken up by forests (Heinrich et al. 2023).

Photosynthetic energy is required for the forming of biomass and carbon uptake from the atmosphere. Jan Pokorny and his colleagues find on average, in the temperate zone, that photosynthetic production leads to the growth of 1 kg of dry matter per year per square meter of vegetation. The photosynthetic energy required to produce that 1 kg of biomass is 4.4 kilowatt-hours (kWh), equivalent to 16.1 million joules over the course of the year, and equal to 0.5 W/m^2. Meanwhile, the energy required for transpiration amounts to approximately 98 J/m^2 or close to 200 times as much. On the basis that most of latent heat transpiration energy is radiated outward to Space when the water vapor condenses, evapotranspiration is far more effective for global cooling than the biomass-sink for CO_2. However, the point is that the two processes, namely, biomass growth and transpiration, act together and in addition to each other. It would be truly synergistic in the sense that more biomass translates into an expanded leaf area and, hence, to more evapotranspiration (Eiseltová et al. 2012).

The extraordinary role of the angiosperm-dominated rainforest in enabling the recycling of rain by means of evapotranspiration is surely some evidence of a Gaia-like relationship between the biota and its environment, including the regulation of regional climate. Indeed, forests, and in particular rainforests, therefore play a vital role in the cooling of the Earth's surface. Not only through the recycling of evapotranspired rain do they provide the necessary watering of forests in the hinterland of continents, they absorb significant solar energy in the form of latent heat which, through the upward flow of humid air, is carried past the greenhouse gas blanket and, on condensation with cloud-forming, gets irradiated as infrared out to Space. That means of cooling is potentially two orders of magnitude greater than achieved by the uptake of carbon for biomass growth. Evapotranspiration cools the leaf surface, thereby preventing the exposed leaves, with their low albedo, becoming scorched. In addition, the closed canopy of the rainforest maintains the high humidity below it, protecting the soil and preventing excessive drying-out (Hodnett et al. 1996).

Forest Cooling

How much more forest would we need to cool the planet? We know from NASA that the current extra warming amounts to 1.81 W/m^2 of the Earth's surface. The Earth's surface in square meters amounts to 510 million-million square meters (5.1×10^{14}). Therefore, the additional global warming of the total Earth surface over the course of a year amounts to the seemingly gigantic number of 2.91109×10^{22} watts. Taking just the latent heat capture of the Amazon rainforest encompassing 5.75 million square kilometers and assuming all that energy is dissipated to Space, we obtain the number 2.92025×10^{22} watts. That number is remarkably close to the extra warming. Theoretically, and adding in the cloud-cooling effect, by reforestation we could cool the planet within a matter of decades. That process would be helped by reductions in greenhouse gas emissions.

For the time being we might want to reduce the additional global warming of 1.81 W/m^2 by close to half, thereby reducing the average surface temperature by 0.9 °C. We could achieve that by restoring an area of tropical rainforest by 2.8 million square kilometers. Already more than one quarter of the Amazon rainforests has been destroyed during the last half century to make way for soya, cattle, palm oil, hydroelectricity schemes, and mining. If we add in the uptake of carbon dioxide in reafforestation, then just the restoration of forests to those regions which have been cleared would, in all probability, meet our target of cooling the planet and thereby reducing the number and severity of extreme weather events, like droughts, floods and scorching temperatures, or even bitter cold, as when the circumpolar air currents push their way to lower latitudes.

In conclusion, the restoration of forests in areas that have been cleared could likely achieve our goal of stopping the planet from heating up further, while reducing extreme weather events such as droughts, floods, and heatwaves. In addition, forest regeneration would mitigate the long-term warming effects of carbon dioxide by biomass-absorption, thereby adding to the global benefits from phasing out fossil fuels.

The Biotic Pump

In 2007, Anastassia Makarieva and Victor Gorshkov from the Petersburg Nuclear Physics Institute came up with a hydrological theory indicating that the pressure reduction as clouds formed over the rainforest would result in a flow of humid air from offshore to replace the upward flow of air over the forest. They claimed that the pressure change would be powerful enough to account for the Trade Winds, flowing for instance from the West coast of Africa to the Amazon Basin. Their theory, the biotic pump theory, would help explain the phenomenon of rainfall being as high over the Colombian Amazon, some 3000 km away from the oceanic vapor source, as over the Eastern Amazon in Brazil (Makarieva and Gorshkov 2007).

If it is the case that forests deep inland and far from the coast depend on the biotic pump to draw in rain-bearing air from the ocean, the effect of widespread deforestation, especially at the coastline, could be disastrous. The severe droughts which affected the Amazon Basin in 2005, 2010, and worst of all in 2023 may be indications that the biotic pump is failing.

In their 2007 article, *Biotic pump of atmospheric moisture as driver of the hydrological cycle on land*, Marakieva and Gorshkov state that precipitation at a particular distance from the oceanic source of humidity (P_x) is equal to the precipitation at the coast (P_0) multiplied by the minus exponential of the distance (x) in kilometers from the coast divided by the average fallout length (l) of a water molecule from its evaporation to precipitation, the latter being given as 600 km in accordance with Salati's isotope measurements:

$$P_x = P_0 \exp[-x/l]$$

If there is good forest cover all the way to the coast, then the biotic pump ensures sufficient rainfall by means both of evapotranspiration and cloud-forming implosion force, the latter drawing in the humid surface flow of air (the Trade Winds). Those twin processes ensure that the supply of humid air above the forest is sustained, with the consequence that the distance a molecule of evaporated water remains in the air appears to extend toward infinity. In fact, if the virtual length of the precipitation pathway of a water molecule extends to 5000 km, the loss in precipitation, even thousands of kilometers distant from the coast, is negligible.

If take the Amazon Basin as an example, the above formula indicates that, following deforestation, the closer to the coast, the more rapid the reduction in precipitation. That simple finding tells us that first and foremost we should take

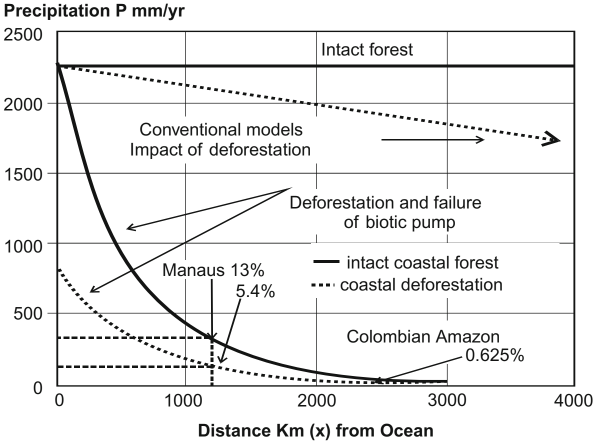

Fig. 5 Widespread deforestation in the Amazon Basin would lead, according to the biotic pump theory of A. Makarieva and V. Gorshkov, to an exponential reduction in rainfall as one passed from the coast to the deep interior. The net result would be desert conditions and not the savannah-like conditions indicated by conventional (without biotic pump) climate models. (©Peter Bunyard) (Makarieva 2007)

good care to protect the forests close to the shore. Indeed, the curve of precipitation loss for a deforested Amazon Basin is exponential with the most rapid decline close to the coast and a leveling off several thousand kilometers later, when the annual rainfall would be no better than that we can expect for a desert as dry as the Negev in Israel (Fig. 5).

Up until now, the great majority of climatologists do not accept the biotic pump, instead insisting that latitudinal temperature differences between the sub-tropics and the equatorial tropics explain the movement of air known as the Hadley Cell Circulation. As a consequence, models of changes to rainfall across the Amazon Basin, as a result of widespread deforestation, indicate the central and western reaches transforming to semiarid savannah. Conventional models, therefore, give a very different result from that predicted on the basis that the watering of the Amazon Basin, especially in the far-western reaches, is contingent on the proper functioning of the biotic pump, which itself depends on good contiguous closed-canopy cover.

Experiments Confirm Biotic Pump Theory

The skepticism that the spread of forests inland depended on a biotic pump to provide the necessary rainfall led Peter Bunyard to devise experiments to determine whether water vapor condensation would lead to a measurable circulating airflow. He therefore designed a 5-meter square 1-meter-wide donut-shaped structure in which he could enclose local air. An industrial refrigerator attached to a 12-mm diameter double-layer of copper piping was used to cool a portion of the enclosed 20 kg of air (see Figs. 6 and 7).

The results of more than 100 experiments under different external weather conditions, ranging from temperatures as high as 25 °C and low as 5 °C, with different relative humidities, indicated that condensation caused by the refrigeration

Fig. 6 The experimental structure for measuring airflow in relation to the rate of partial pressure change as a small portion of air passed over the cooling coils and the contained water vapor condensed. The cooling coils seen from looking up the right-hand column. How much air was cooled per second depended on the rate of condensation and the resulting airflow. With no condensation there was no measurable airflow, even though the air at the cooling coils showed a temperature reduction of 10 °C and a gain in density of 0.05 kg/m^3. (©Peter Bunyard 2024)

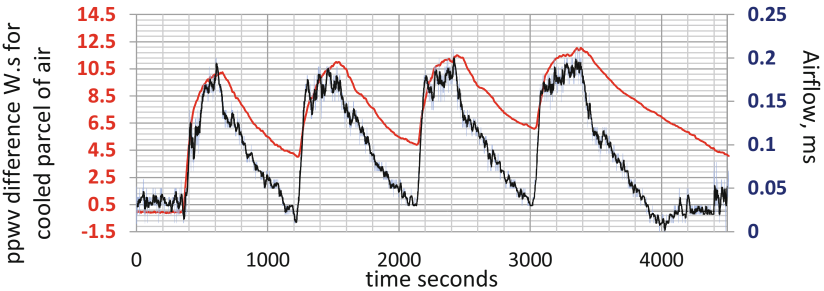

Fig. 7 Experiment June 27, 2016. The graph shows four refrigeration cycles. The left-hand axis shows the partial pressure change in water vapor in watt seconds during the refrigeration cycle and the right-hand axis shows the anemometer readings in meters per second. (©Peter Bunyard 2019)

at the coils of a small parcel of air inevitably led to measurable airflow. Should the relative humidity be low, for instance, below 60%, such that cooling of the air parcel failed to bring about saturation and condensation, then no airflow could be detected even though the parcel of air had cooled by 10 °C relative to the average air temperature in other parts of the structure. That finding, in contrast to experiments where condensation was detected by ensuing rainfall and its collection, indicated that unidirectional airflow was a necessary correlation of condensation (Bunyard et al. 2017, 2019).

From the physics, using sensors to provide temperature (in kelvin), barometric pressure (in hectopascals), and relative humidity, the partial pressure change (in hectopascals and watts) according to the rate of condensation could be determined. Under the physical conditions of the experiments, gravitational changes in air density of the cooled parcel of air were compared with the energy associated with the implosion of air, as condensation took place. The gravitational energy associated with air density was found to be at least 1000 times weaker than the implosion energy associated with condensation, such that the air density change could not account for the measured airflow around the chamber (Bunyard 2014; Bunyard et al. 2017, 2019).

The mechanical physics of implosion therefore dictate that a prime consequence must be airflow. In conclusion, evapotranspiration over the rainforest and the subsequent forming of dense clouds act to draw in surface air from the same latitude ocean, which therefore replenishes the moisture that has precipitated out over the rainforest. And the apparent movement of the Sun from East to West will move the process of evapotranspiration and the cloud-forming with it across the entire Basin, thereby conferring continuity to the process and helping to generate the Hadley Cell mass circulation over the equatorial tropics.

Catastrophic Corroboration from the Time of Colonization

Our claim that forests cool the Earth is given credence by a recent study of the cause of the mini-ice age during the seventeenth and eighteenth centuries, when, for example, the Thames in London froze over sufficiently for ice-skating. Alexander Koch and colleagues showed that the global carbon budget of the 1500s cannot be balanced until large-scale vegetation regeneration in the Americas was included. The Great Dying of the Indigenous Peoples of the Americas resulted in a human-driven global impact on the Earth System in the two centuries prior to the Industrial Revolution. Koch and his colleagues estimated that 55 million indigenous people died following the European conquest of the Americas beginning in 1492. Deadly disease therefore led to the abandonment and secondary succession of 56 million hectares of land which led to an additional 7.4 Pg C (7.4 gt of carbon) being removed from the atmosphere and stored on the land surface in the 1500s. Overall, including feedback processes, forest grow-back contributed between 47% and 67% of the 15–22 Pg C (15–22 gt of carbon and equivalent to 7–10 ppm of atmospheric CO_2) decline in atmospheric CO_2 between 1520 CE and 1610 CE seen in Antarctic ice core records. Koch and colleagues concluded that the Great Dying of the Indigenous Peoples of the Americas led to the abandonment of enough cleared land in the Americas that the resulting terrestrial carbon uptake had a detectable impact on both atmospheric CO_2 and global surface air temperatures in the two centuries prior to the Industrial Revolution (Koch et al. 2019).

Koch and colleagues, in their excellent analysis, did not take into account the potentially much more effective cooling from latent heat transport as the regenerating forest restored the condensation/biotic pump function and enhanced its evapotranspiration.

Once we include latent heat energy transfer in calculations as to how much more forest would need to be recovered to offset the current global warming of 1.81 W/m^2, we find, as we pointed out earlier, that an area equivalent to the Brazilian Amazon Basin would be required, namely, 5.75 million square kilometers. In fact, we might be able to settle climate to a more equitable regime by reforesting some 2.5 million square kilometers of degraded regions across the tropical zone of the planet. Just over the past 50 years, at least one-quarter of the Amazon rainforests have been decimated and even more has been degraded. Similar degradation has taken place in Africa and Indonesia, let alone in Canada's British Columbia. A concerted effort to restore closed-canopy, biodiversity-rich forests has to be a priority in the battle to cool the climate.

The Critical Role of Aerosols in Stabilizing the Climate

Recently, the effect of aerosols on global temperatures has become a hot topic in discussions around climate change. Ironically, the attention has come through a certain spike in ocean temperatures attributed to the new strict sulfur norms in shipping fuel, which has led to a dramatic decline in the sulfur carrying aerosols coming from global shipping, leading to an increase in the Earth's energy imbalance of several watts per square meter, because of less cloud formation and less scattering by these aerial particles.

Paul Crutzen, Nobel Prize winner for his work as an atmospheric chemist, was one of the first to appreciate the role of bio-aerosols in bringing about the formation of clouds and resulting rainfall. Bio-aerosols, such as isoprene, terpene, and dimethyl sulfide, emitted from trees and oceanic coccolithophores, play an important role in cooling the climate through their cloud-forming attributes. The destruction of rainforests has led, therefore, to a significant reduction in such aerosols, with the net result an accentuation of the global warming that is now being experienced worldwide. Warm the world by removing aerosol emissions and this will create more extremely hot days, more extreme precipitation events, and more consecutive dry days over highly populated regions.

Indeed, aerosols play a key and almost completely overlooked role in weather, precipitation, cloud formation, and influencing the Earth's energy balance and climate system. Aerosols also exhibit high climate sensitivity, meaning that they can mask a considerable amount of the warming effect caused by greenhouse gases. This heightened sensitivity is attributed not only to their distribution across the globe but also to their specific interactions with the land surface at local scales.

With efforts toward carbon neutrality and stricter control of anthropogenic emissions, the future is likely to see a significant decrease in anthropogenic aerosol emissions and their precursors. This reduction is expected to have notable regional climate effects, such as influencing the South Asian summer monsoon and potentially increasing flood risks. Additionally, substantial reductions in aerosols could intensify heat extremes in areas like China and Europe. But what is missing from the whole discussion is the primary role that the aerosols play as part of creating the metabolisms of the Earth for life to thrive, which have been evolved by the biosphere. Aerosols are life's key ingredient in creating planetary homeostasis.

Bio-aerosols in particular play a crucial role in the formation of clouds and rain by serving as cloud condensation nuclei and ice-nucleating agents. These airborne biological particles provide surfaces for water vapor to condense upon, forming cloud droplets. Certain types of bio-aerosols, like specific bacteria, are particularly effective at initiating ice formation in clouds due to their unique surface proteins. As these droplets or ice particles grow in size, they eventually fall as precipitation. Aerosols also scatter light cooling their area and, in some cases, like black carbon from forest fires, and anthropogenic activities can actually warm the atmosphere locally because they absorb radiation.

While the science of aerosols is very recent and there are a lot of unknowns, the authors like to stress that aerosols and their interaction with the atmosphere and the atmospheric water cycle in particular have evolved over hundreds of millions of years, and we can therefore assume, operating from the Gaia Theory, that the aerosols emitted by each ecosystem are different and are attuned to their role in creating the right climatic conditions for the colonization and stabilization of the areas from which they have originated, like the tropical rainforest or a phytoplanktonic bloom. It is typical for our human-focused observations to now wake up to their effect, as we are partly responsible for their creation or removal, but first and foremost, it is important to realize the role that bio-aerosols, created by nature, have played for a very long time in shaping weather and climate.

Aerosols in the atmosphere can be biologically or non-biologically sourced. Biological aerosols or bio-aerosols encompass a variety of particles such as bacteria, which can be either harmless or pathogenic, viruses that are often attached to other particles for transport, and fungi, including spores and fragments prevalent in environments like agricultural fields. Pollen grains, contributing to seasonal allergies, along with various fragments of plant and animal debris, also fall into this category, as do less common entities like protozoa and algae, particularly found near water bodies. In the main, bio-aerosols function as cloud condensation nuclei (CCN), upon which water vapor condenses to form cloud droplets. Given their importance in converting water vapor (a greenhouse gas) into liquid droplets or ice crystals, bio-aerosols are essential for cloud formation. Because of albedo changes, clouds formed with the help of aerosols influence the Earth's radiation balance and therefore climate. By a raised albedo, such clouds reflect solar radiation; moreover, the phase change from vapor to liquid raindrops and ice particles releases latent heat as sensible energy which can now irradiate to Space. Net cooling of the atmosphere is the result and forests emitting aerosols are therefore major climate mitigators.

An important climate stabilizing bio-aerosol is dimethyl sulfide (DMS). DMS contributes to climate stabilization through its role in cloud formation. When DMS is released from phytoplankton in the ocean, it enters the atmosphere where it gets oxidized, forming sulfate aerosols. These aerosols act as cloud condensation nuclei, which are crucial for cloud formation. More clouds increase the Earth's albedo, reflecting more sunlight back into space, thereby cooling the Earth's surface. This process was first been described in the CLAW hypothesis, in which James Lovelock and others posed the feedback loop where increased phytoplankton activity leads to more cloud formation and potentially moderates global temperatures. This is an excellent example as to how the largest biome in the world, the ocean, creates a planetary-scale homeostasis mechanism. Homeostasis is a process by which biological systems maintain stability, despite external changes, while adjusting to

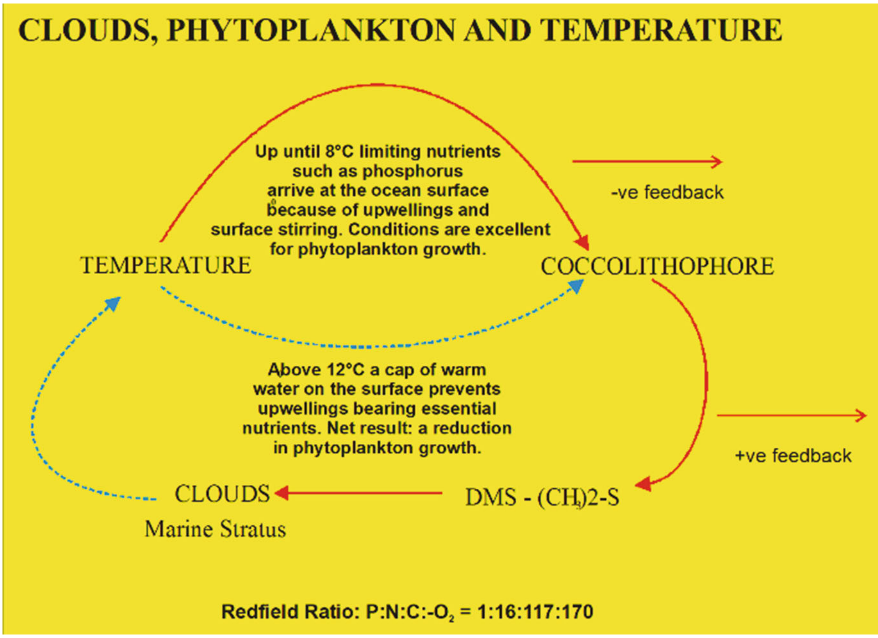

Fig. 8 The CLAW hypothesis: direct relationships are solid, red connections; inverse relationships are blue, dotted connections. The greater circle with just one inverse connection results in negative feedback. The smaller circle with two inverse connections results in positive feedback. (From Lovelock 1979 – graphic Peter Bunyard)

conditions that are optimal for survival, thus regulating temperature, pH, salts, and distribution such as to bring about the phenomenon of the Redfield ratio, whereby phosphorus to nitrogen to carbon to minus-oxygen is 1:16:117:170 (Whitfield 1996) (Fig. 8).

The water cycle and aerosol production over the great rainforests also work as homeostasis mechanisms, stabilizing the climate over large part of whole continents and even beyond.

Apart from biological aerosols, all kinds of other particles like dust, often raised by wind and capable of long-distance transport, and sea salt particles formed from evaporating ocean spray, also influence the climate. Sulfates and nitrates, resulting from industrial emissions of sulfur dioxide and nitrogen oxides, are also significant, as is black carbon, a product of incomplete combustion of fossil fuels and biomass and last but not least volcanic ash, which can have far-reaching impacts on the climate. A famous example is the Mount Pinatubo eruption in 1991 in the Philippines, which had a significant cooling effect on the Earth's climate. The eruption injected large amounts of volcanic ash and sulfur dioxide into the stratosphere, forming aerosols that reflected sunlight away from the Earth. This led to a decrease in global temperatures by about 0.5 °C (0.9 °F) in the years following the eruption. This cooling effect lasted about 2 years before temperatures returned to pre-eruption levels. Further back in history the much larger Lake Toba eruption on the island of Sumatra, which occurred about 70,000 years ago, is widely believed to have caused a volcanic winter, with temperatures dropping by several degrees Celsius for a period of several years. The eruption's impact was so substantial that it is thought to have affected global ecosystems and human populations.

As we are seeking ways to stabilize the climate apart from reducing greenhouse gases, aerosols become big news. The current Earth energy imbalance is around 2 W/m^2 or approximately 1% of the total incoming sunlight, which does not straight away reflect off the atmosphere. Recent research puts the decrease in global low cloud level at 1.5%. The restoration of our heavily degraded ecosystems will go a long way to reverse these imbalances. In any plan to really tackle the climate crisis, these elements must be part of the equation. While we could imagine human-triggered aerosols to play a role in the temporary cooling of the planet, the real and overwhelming role to regain homeostasis falls again to the restoration of biosphere and a strong enhancement of bio-aerosols. Ecological restoration of all biomes will have significant, fast cooling and calming effects on the world's temperatures and weather extremes.

We Can Stop Global Warming Fast

Reducing emissions must continue, but the main focus needs to shift to the repair of nature and water cycles around the world, together with massive increases in regenerative agricultural practices and agroforestry to make landscapes climate-resilient. Combined with reviving ocean biology, it will restore a balanced climate, calm the weather, and cool the planet! Tens of gigatons of CO_2 per year will be sequestered in the fast-increasing living biomass around the world. The transition of an area of 2.5 million km^2 in the tropical belt from open field to forest or agroforestry will increase the cooling capacity through the atmospheric water cycle enough to stop the planet from heating up further.

While humans may be able to adapt to some extent to different climatic conditions, it is especially our globally interconnected complex and highly technological societies that are at risk. To protect both our highly technological complex human societies and the environment, it is crucial to mitigate climate change and adapt to its impacts. This is necessary to ensure a sustainable and resilient future. We must make the case that the move to a sustainable future is possible and achievable within a relatively fast timeline, if we wake up to how the climate really works and act accordingly.

While the world is currently obsessed by the increasing amounts of carbon dioxide in the atmosphere, our activities have impacted on the atmosphere in many more ways, including greenhouse gas emissions other than carbon dioxide, aerosol pollution from industry, agriculture and our transport systems, ozone depletion because of emissions of the CFCs, and air pollution from changes to land-use creating more dust and diminishing humidity. All these diverse activities, taken together, are affecting the health of ecosystems, animals, and humans alike.

We have now increased the global temperature by 1.4 °C, which is the combined result of greenhouse gas emissions from fossil fuel burning and from our destruction and degradation of essential ecosystems, especially forests, and just that seemingly small rise in temperature has led to the spate of extreme climate events which we are currently experiencing, including the heat waves and outbreaks of fires that devastated Greece and elsewhere across the Northern Hemisphere during July, 2023, followed in Greece by record-shattering rains and unprecedented floods in September of that same year. All such extreme and devastating events underscore the escalating challenges posed by extreme weather events in the era of climate change. We could easily list dozens of similar devastating events from around the world which clearly have the fingerprints of increasing climate volatility all over them. Without fast, global action to cool climate chaos, which includes the restoration of ecosystems at an unprecedented scale, human society will swiftly become fragile, brittle, and incapable to recover from not just the immediate effects but also from second-round effects such as destroyed harvests, insect infestations, epidemics, disrupted economic activities, high inflation, increased health issues, strained social services, displacement, migration, and exacerbated inequalities and social, political tensions, violent conflict, and war.

By far the largest impact on climate, for which we are responsible, has resulted from extreme land-use change and the destruction of ecosystems. That worldwide destruction has altered drastically the flow of water vapor from its evaporation and precipitation, all of which has had a profound effect on atmospheric hydrology and the flow of water locally and globally from ocean to land and back to ocean. The transformation of water through its phases from ice and liquid to vapor and back to liquid is the Earth's major transporter of the Sun's energy from the Earth's surface to outer Space, and we have to thank this fundamental role of water in cooling the planet. Moreover, such cooling has taken place, despite the Sun being 30% more luminous and energetic than it was 4.5 billion years ago, when the Earth first formed. Cloud-forming over both land and ocean has been significantly enhanced because of transpiration and because of the emission of aerosols, such as dimethyl sulfide, oxidized by hydroxyl to SO_2, and terpenes, all of which are excellent cloud-condensation nuclei. In effect, the evolution of life on Earth has gone hand-in-hand with the regulation of the Earth's surface temperature, both by regulating the flow of water and by forming biomass from atmospheric CO_2, such that it has never become too hot or too cold, even taking account of cataclysmic events like the Chicxulub asteroid strike of 66 million years ago.

From the time of the neolithic revolution some 12,000 years ago, when we started farming and creating long-term settlements which became ever more grandiose cities, we humans have disturbed the flow of water across the surface. A reduction in evapotranspiration means a significant reduction in the total amount of sunlight energy taken up as latent heat in the transformation of liquid water to water vapor. The ratio, the Bowen ratio, between the amount of solar energy which can directly heat the surface and the amount of solar energy which is carried away in the transpired water vapor, increases significantly and results in the heat of the Sun remaining trapped at the surface rather than cooling the surface as water is evaporated. Even when exposed to direct sunlight, we can perceive the temperature difference between a vegetated, transpiring surface and a hard surface free of all vegetation. The temperature difference can be as much as 20 °C.

The opportunity we have to avoid wholesale collapse of global human society is small and shrinking by the day, but there is an outside chance that we can still turn it around once we understand that we are an integral part of a living planet and that, with such understanding, comes the responsibility of caring for a biosphere which has created the conditions for life and ourselves to thrive. Care and good stewardship of the natural world, with its essential ecosystems, needs to become our highest priority.

At talks in Egypt on curbing global warming in November, 2022, UN Secretary General Antonio Guterres warned world leaders that “we are in the fight of our lives.” What he did not say was that caring for the Earth, the land, the soils, the plant life, and biodiversity everywhere, while drastically reforming our lifestyles and food production methods, could get us out of the mess we are in within years rather than decades, assuming we somehow found the clarity of mind and the political will to do so. Only by that can we avoid the worst genocide in the history of our species or as Antonio Guterres calls it: our collective suicide. Therefore, we absolutely need a widespread planetary movement to enable the Great Turn-Around with a clear list of emergency actions to first of all avert the passing of irreversible tipping points such as the dieback of the Amazon rainforest, the consequences of which would overwhelm any amount of action. That movement must operate from a planetary perspective in the short-term before wholesale collapse of human societies becomes irreversible.

Understanding the Urgency to Avert Collapse

Since 2019 there has been much talk about the climate tipping points, which are critical thresholds at which complex systems can pass a certain limit-triggering significant, sudden and often irreversible change in the state of a part of the Earth’s climate system. Once this threshold is crossed, the change becomes self-perpetuating, leading to potentially large-scale and unpredictable cascade of deteriorating climatic conditions and damage to the Earth’s biosphere, which often take the form of self-reinforcing feedback loops. Professor Johan Rockström, director of the Potsdam Institute, warns that the world is heading toward 2–3 °C increase in global warming, risking multiple disastrous tipping points and cascading the world into a future which is uninhabitable for our current number of people. Recent studies show destabilization in the Amazon rainforest, Greenland ice sheet, the West Antarctic ice sheet, and Gulf Stream currents that are well underway, with profound implications for global climate and biodiversity (Lenton et al. 2019).

These self-reinforcing feedback loops can start at a snail’s pace and then suddenly accelerate and become unstoppable. For instance, melting polar ice reduces the Earth’s albedo (reflectivity), leading to more heat absorption leading to less polar ice, leading to reduced albedo and further warming, and so on. Or deforestation changes weather patterns and precipitation, which can lead to the drying out and warming up of large regions, leading to more tree dieback, leading to additional warming.

The Intergovernmental Panel on Climate Change states that the risk of triggering tipping points becomes high with 2 °C of global heating, but the authors of this chapter believe that it is possible that we may already have passed irreversible thresholds. It is simply too early to know as the changes might be in a blink of an eye on evolutionary timescales. Certainly, for humans, awareness of the climate crisis may barely have registered as the changes are still very localized and slow on a human timescale.

This difficulty to perceive degradation over longer periods of time is called "shifting baseline syndrome" by which people perceive the environmental conditions they encounter during their youth as the norm, that being their personal worldview. As such, they may discard their grandparent's stories about enormous fish catches as fantasy, making it difficult for them to apprehend how abundant nature was just a couple of generations ago, or to take into account the size of the destruction we have meted out on a decadal timescale. As Milner-Gulland has stated, "If we don't realize what we are losing we stand the risk of sleepwalking through the destruction of the natural world without taking action to remedy the situation" (Hance 2009).

While people perceive more extreme weather, crop losses, floods, and hot days, it is difficult for most to understand that the Earth has already exited a "safe" climate state in which human civilization and agriculture developed. We have left that safe zone not just because of increased temperatures, but even more because of shifting weather patterns which have undermined the resilience of our societies, with impacts on health and social stability. The simultaneous human-induced changes to atmosphere, oceans, forests, freshwater bodies, soils, and biodiversity have degraded the resilience of the whole biosphere. In effect, we have brought about a serious deterioration of our global system to absorb stress and bounce back from increasingly occurring extreme weather events.

The gradual deterioration of the biosphere, when passing certain thresholds, will lead to a sudden decline or ecosystem collapse, thereby preventing the system from rebounding to a previous state. The dieback of the Amazon rainforest is one such example. Other examples which we have already seen are events like coral bleaching and seagrass meadow die-off or the spread of ocean dead zones. Ocean acidification, once passing a threshold, will disrupt the whole marine food chain (McSweeney 2020).

The climate tipping points include the melting of Arctic sea ice, collapse of ice sheets in Greenland and West Antarctica, thawing of permafrost, destabilization of the Amazon rainforest, die-off of coral reefs, and shifts in ocean currents like the Atlantic Meridional Overturning Circulation.

Operating from the vision of the planet as a single integrated organism, we must address these intertwined ecosystem degradations in a holistic way, with an understanding that the health of the parts is connected to the health of the whole. Addressing global warming must be seen in the context of the larger crisis which is the crisis of the biosphere caused by the damage inflicted by the billions of humans carelessly exploiting this once resilient body of integrated life. Only a comprehensive approach with a view of the functioning of the whole planet will have any chance of success of averting the worst-case scenarios which are already beginning to manifest themselves. We have to understand the urgency of the situation and take action from the viewpoint of risk management by which we adopt strategies that prioritize global safety and stability, without necessarily understanding the whole picture. Right now, we are moving too slowly and are too reticent and myopic to deploy a series of comprehensive measures at the right scale and speed to avert global collapse. We must shake ourselves out of the notion "let's wait and see," because the windows of opportunity to bring about effective action are rapidly closing. Based in the conviction that we are already in the danger zone and need to act fast to be able to avert the worst-case scenario, we must act, at a sufficient scale and speed, to confront the current crisis, by prioritizing actions that will help stabilize the fast-deteriorating situation on our planet.

Emergency Priorities to Stabilize the Planet's Climate

1. Avert the **tipping point of die-back of the Amazon rainforest** and strategically reforest the biome to restore the full vigor of the biotic pump function over the area, for fast regrowth of huge forest areas in the Americas and a transition to agroforestry food production.
2. Create and apply a global plan for the **fast revival of ocean biology in strategic locations** including the fertilization of ocean deserts to sequester carbon, restore the ocean food chain, increase vertical mixing of the water column, increase planetary albedo through increased aerosol production and cloud formation.
3. **Green the desert areas** from the Thar Desert to the Sahara and the drying-out Mediterranean through strategic ecosystem regeneration, with the aim of connecting the Indian monsoon moisture stream with the West-African monsoon. Strategic reforestation over the Indian subcontinent will likely **increase precipitation on the Third Pole,** the range of high mountains (the Himalayas) connecting the Indian subcontinent to China.
4. We must deploy methods that will help **reverse polar amplification** by reversing the melt of polar sea ice on both sides of the planet.

But How Much Do We Have to Do to Reverse Climate Chaos?

To stop further warming within 20 years and reduce extreme weather events, we need a strategic plan involving the global population, powerful institutions (governments, armed forces, corporates, etc.), and place-based solutions. We must also operate from a risk management perspective, acting at a necessary scale and speed to avert collapse of societies. Key priorities include the following:

- Supporting, via finance, information and tools, 500 million indigenous and smallholder families worldwide, mostly in the Global South, to transition to regenerative agroforestry food production and protect remaining forests and ecosystems NOW! This will restore small water cycles, regenerate soils, protect biodiversity, and increase living biomass. According to our calculations regenerating vegetation on 250 million hectares of land in the tropics, transitioning to agroforestry or reforested area will stop the planet from heating up further.

  The estimated cost is 0.5% of Global GDP or around 500 billion dollars per year for 20 years.
- Mobilizing large networks of organizations, such as Rotaries, Red Cross, Oxfam, and climate action groups, to support communities in regenerating local ecosystems and improving their well-being.
- Implementing an ocean and coastal marine ecosystem restoration program, delivering nearly immediate positive socioeconomic results. We already know how to do this, with an estimated cost in the tens of billions of dollars.

After a period of perhaps 20 years of emergency regeneration as we move back from the brink of collapse, new generations can build a sustainable future on our beautiful living planet and continue the amazing journey of evolution to new heights we can only dream of.

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