# Cooling the Climate

## *How to Revive the Biosphere and Cool the Earth Within 20 Years*

By

**Peter Bunyard and Rob de Laet**

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# Acknowledgements

This book is the culmination of years of research, and countless conversations about the most pressing challenge of our time: the existential crisis facing humanity. Our concern for the future of humanity started in the 1960's for Peter and for Rob in the 1970's. This book was written by Peter Bunyard and Rob de Laet based on a publication that Peter first wrote in 2010.

We are standing on the shoulders of many brilliant and passionate people, some of whom hover over this book in spirit, such as the great scientist James Lovelock, and the Aborigine leader Guboo Ted Thomas, a crucial mentor for Rob.

A special thank you goes to the founders of Climate Change and Consciousness, Stephanie Mines, the chairperson of Biology for a Livable Climate, Philip Bogdonoff and the co-founder of EcoRestoration Alliance, Jon Schull and members of the EcoRestoration Alliance.

Last and not least, we want to express deep gratitude to Nature and Mother Earth, for giving us the greatest gift of all, Life. What a Wonderful Journey it is! ''You may say I'm a dreamer, But I'm not the only one. I hope someday you'll join us, And the world will live as one'' John Lennon, Imagine.

Together, we can make a difference and we must, because we are running out of time.

"Look closely at nature. Every species is a masterpiece, exquisitely adapted to the particular environment in which it has survived."

— Edward O. Wilson

# Preface

The pressing question today is whether we can cool the planet and stabilize the climate within twenty years. The answer lies not just in reducing greenhouse gas emissions but in rethinking our approach to nature. The planet's water cycle, powered by plants, plays an underappreciated but crucial role in climate regulation. While carbon emissions dominate the conversation, the interaction between water, plants, and the atmosphere is equally essential in cooling the planet. If we can restore degraded ecosystems and revive natural processes like evapotranspiration, we can tackle the climate crisis.

Life on Earth has spent billions of years co-evolving with its surroundings, building ecosystems which through multiple interactions, help maintain a stable climate. The planet has faced mass extinctions before, yet life has always found a way to rebalance itself. Today, with the climate crisis driven largely by human actions, we need to accelerate the restoration of these natural systems to stabilize the climate.

## A Call to Action: Reimagining Our Role in Planetary Health

In our book, we argue that to truly reverse the climate crisis, we must repair the planet's ecosystems and restore the balance between water, plants, and the atmosphere. This approach, inspired by the Gaia theory of James Lovelock, suggests that Earth is a self-regulating organism and that, by working with natural processes—such as photosynthesis and water cycling, we can cool the planet more effectively than by focusing almost exclusively on carbon reductions.

The key lies in leveraging the power of nature. Regenerating forests, restoring water cycles, and expanding regenerative agriculture are critical strategies. These natural processes not only sequester carbon but also have a profound cooling effect on the planet. We propose a strategic plan that involves both global and local actions to restore ecosystems and stabilize the climate.

## Part I: The Science Behind Cooling the Planet

Our book begins by delving into the science of how the planet regulates its temperature through natural processes. Plants and ecosystems are central to maintaining this balance. When we destroy ecosystems—through deforestation, industrial farming, or urbanization—we disrupt these processes and accelerate global warming.

One crucial concept we explore is the biotic pump, originally a theory, but now a principle, that shows how forests generate rainfall and maintain atmospheric circulation. This process begins with evapotranspiration—plants releasing water vapour—which leads to cloud formation and rainfall. In the Amazon, for instance, this cycle is responsible for much of the rainfall across the continent and for the formation of atmospheric rivers of moisture. Deforestation breaks this cycle, leading to droughts, reduced rainfall, and ultimately ecosystem collapse.

In the appendix, we highlight research by Peter Bunyard, who proved experimentally that water vapour condensation in the formation of clouds leads to a measurable airflow, validating the biotic pump theory. His experiments demonstrated that forest evapotranspiration is key to maintaining rainfall patterns far from ocean sources, ensuring the survival of forests and farmlands even thousands of kilometres inland as is the case for the Amazon and Congo Basins.

## The Role of Water in Cooling the Planet

Water is an essential part of the Earth's temperature regulation system. As we all know from watching a kettle boil, a lot of energy has to go into steam-making. Plants, in releasing water vapour from their leaves, use the sun's energy to bring about that vaporization. The evapotranspired water vapour rises into the atmosphere, where it cools, condenses into clouds, and releases the latent heat energy needed for vaporization, which escapes into space as infrared radiation. This process not only cools the surface but also creates the necessary conditions for rainfall and climate stability.

The Amazon rainforest plays an outstanding role in this process. It acts as a giant natural heat pump, drawing moist air from the Atlantic Ocean and recycling it across the continent. However, deforestation threatens this delicate balance, potentially leading to the collapse of the rainforest and a significant disruption of global climate patterns. It may well be that the terrible droughts which afflicted the Amazon Basin during 2023 to 2024 can be tied, in part at least, to the spate of hurricanes and tornadoes which wreaked so much damage and loss of life during the autumn of 2024 in Florida. The lack of rain to the Amazon indicates a significant weakening of the Trade Winds which, in a normal year, are responsible for 40 per cent of Amazonian rainfall, the rest, some 60 per cent, being provided by a forest-led recycling. To provide the rainfall coming in with the Trade Winds, as much as the equivalent of 5.5 atomic bombs of energy per second are required of the Sun's radiation to warm the surface of the tropical Atlantic Ocean, such as to bring about evaporation. The faltering of the Trade Winds therefore results in a significant proportion of that heat being retained over the ocean. That extra energy is available for hurricane formation and not surprisingly we have Hurricane Milton following hard on the heels of Hurricane Helene.

## Part II: Challenges and Solutions—A Global Blueprint for Restoration

In this section, we provide concrete strategies for large-scale ecosystem restoration. To cool the planet, we propose a combination of reforestation, regenerative agriculture, and the restoration of degraded lands and watersheds. These actions are urgently needed to address the ongoing destruction of ecosystems, which is contributing to climate chaos.

We emphasize the importance of focusing on bioregions and watersheds—natural boundaries defined by ecological and hydrological systems. Restoration projects based on watersheds can simultaneously improve water quality, regenerate biodiversity, and protect communities from the impacts of climate change. A great example is the Subak system in Bali, where communities manage natural resources collectively, leading to sustainable conservation and agricultural productivity.

## Global Priorities: Large-Scale Restoration

1. Avert the tipping point in the Amazon: We call for a global effort to restore the Amazon rainforest, employing over a million workers to replant and regenerate the region. The Amazon's survival is critical not just for South America but for global climate stability.

2. Restore ocean ecosystems: A plan to revive ocean biology through projects like fertilizing ocean deserts to sequester carbon and increase cloud formation. Ocean restoration is vital to regulating climate and maintaining the planet's albedo.

3. Greening deserts: Initiatives to green areas from the Sahara to the Mediterranean can help rehydrate the land, draw in atmospheric moisture, and reverse desertification.

4. Reverse polar amplification: Although this is a more speculative project, we propose exploring both nature-based and technological solutions to reverse the melting of polar ice caps.

## Part III: How We Can Solve the Climate Crisis Within Our Lifetime

The last part of the book focuses on the urgency of reversing climate chaos and the need for international cooperation to tackle these challenges. While local actions are critical, global coordination and financing are required for large-scale restoration efforts.

One of the most immediate actions we propose is a global movement to empower 500 million smallholder farmers to transition to regenerative agriculture. This transition would regenerate soils, restore small water cycles, and increase biomass, with the potential to mitigate climate change significantly. We estimate that this project alone would cost 0.5% of global GDP annually for the next twenty years.

In addition to land restoration, we propose a plan for large-scale ocean and marine ecosystem restoration. This could be achieved through international cooperation and funding, with the goal of restoring coastal ecosystems and reversing ocean degradation.

## A Global Call to Action

Our book is a call to mobilize the best minds and resources to restore the planet's ecosystems and thereby stabilize the climate. By acting together—locally, regionally, and globally—we can create the conditions for the Great Turnaround. We must shift from an economy based on resource extraction to one that regenerates the planet and ensures long-term climate stability.

The stakes are high, but the potential for success is real. By restoring forests, watersheds, oceans, and agricultural lands, we can reverse much of the damage caused by human activities and create a sustainable future for all species on Earth.

We conclude by emphasizing that the solutions to the climate crisis are within reach. With the right strategies, financial support, and global cooperation, we can repair the climate and ensure a liveable planet for future generations.

## Final Thought: Let's Repair the Planet Together!

This book is more than just a scientific exploration of climate solutions. It is a call for action—an invitation to work together to heal our wounded planet. By rethinking our relationship with nature and acting now, we can reverse climate chaos and build a future based on abundance, balance, and respect for the Earth.

# Introduction

Greenhouse gases heat up the planet, but they are not the major driver of climate change. While carbon gets most of the attention, another huge factor is largely overlooked which concerns water in its movements and changes of state (ice, liquid water and vapour) as it interacts with plant life and the atmosphere. This interaction has enormous stabilizing and cooling effects. Once we understand the full force of plants and the water cycle, we can confront the climate crisis with a whole new set of powerful, additional measures. Plants, healthy soils, and healthy ecosystems stabilize weather, and help balance the climate temperature such as to reduce extremes.

Life, through its co-evolution with the surface of the planet, has evolved strategies over the course of 3.8 billion years to create the conditions for life to thrive, even though that has meant overcoming five great mass extinctions. Life has altered the composition of the atmosphere, constantly producing the oxygen we breathe and recycling carbon into the ground. The shells of microscopic skeletons of plankton have even formed whole landscapes, such as the White Cliffs of Dover! Life, with all its different ecosystems, has been balancing the climate for aeons and now, given all the destruction we humans have wreaked, we must help it to do so again. In fact, the whole planetary climate regulation has all the hallmarks of a self-regulating supra-being which, in a nutshell is what James Lovelock called the Gaia Theory. Frontloading vigorous protection and regeneration of nature around the world, together with massive increases in regenerative agricultural practices and agroforestry, will restore a balanced climate, calm the weather and cool the planet!

*We can leverage these qualities to fight the climate crisis.*

The book will show how we can stabilize the climate and even get on a trajectory of cooling. It shows that if we intervene with Nature's intelligent methods, we may avoid average global temperatures exceeding the 1.5$^0$C limit of rising temperatures, set by the IPCC as the point beyond which climate change and the extremes will become increasingly unmanageable.

Regeneration of essential ecosystems, and in particular forests, will have enormous beneficial impacts, including fundamental changes to the flows of energy implicit in the restoration of nature, such that such beneficial changes will result in the Earth cooling, while simultaneously countering to a great extent the global warming caused by anthropocentric emissions of greenhouse gases. The shortest way to describe what we need to do is to stimulate the increase of biomass in the coming two decades in a strategic way to stabilize the climate. The book will also touch on the strategies that are meant for humanity to undertake this largest endeavour in history at the speed and scale needed for it to be successful.

The second part of the book came out of a six-month writing group of the EcoRestoration Alliance, a global network of several hundred scientists, earth stewards, storytellers and grassroots leaders working to accelerate the restoration of degraded lands and waters, foster biodiversity, and cool the planet. The group came together to write a blueprint for a complete regeneration of the Earth's biology to restore its metabolisms, temperature regulation. All biomes can be restored fast. Collectively we have the knowledge.

But we are running out of time. When fluctuations become too extreme, they break through the barriers of balancing that are key to the survival of all life. The authors are all too conscious that we are already at the tipping point of cascading collapse of the life systems upon which humanity is completely dependent. At the same time, we share the hope that nature is incredibly resilient and can bounce back from destruction in remarkably vigorous ways when given a chance and strategic support.

We start with an opening poem, to express our heartfelt pain and anguish for the young, who have inherited a damaged Earth. Do watch and listen. We hope that the knowledge in this book will contribute to reversing the existential threat.

Requiem for the Earth, the Children's Song, *Paco Peña,* original words in English by Peter Bunyard – https://youtu.be/boUu4pPfR6w

## ALABANZA: RÉQUIEM POR LA TIERRA

| | |
|---|---|
| Ay! de tí, hombre villano,<br>¿Qué has hecho con la tierra?<br>¿Dónde están las florestas,<br>Los límpidos arroyos,<br>el transparente mar? | *What of you, uncaring Man*<br>*What have you done with the Earth?*<br>*Where are the forests*<br>*The limpid streams*<br>*The transparent sea?* |
| Has truncado la vida<br>al árbol que,<br>orgulloso,<br>de la tierra salía. | *You have truncated the life*<br>*of the tree which,*<br>*With pride, rose up*<br>*from the Earth*. |
| Has pelado montañas;<br>y los ríos majestuosos<br>hoy ciénagas serán. | *You have laid bare mountains,*<br>*And the majestic rivers*<br>T*hey are becoming unpalatable*<br>*swamps* |
| Ahora llegan torrentes<br>que desbordan el río<br>y arrasan la ciudad.<br>Las casas,<br>el ganado,<br>hombres, mujeres, niños<br>todo perecerá. | *Now, we bear the brunt of torrents*<br>*Which burst the banks of rivers*<br>*And wipe out the city,*<br>*Houses, cattle, men, women,*<br>*children.*<br>*If we don't take care of our*<br>*Sacred Mother, All will perish.* |

# Part One
# The Science Behind Cooling the Planet

## Chapter 1

# The Urgent Need to Cool our Planet

*"If you want to make major changes, you have to change the way you SEE things."*

*"I speak as a planetary physician whose patient, the living Earth, complains of fever; I see the Earth's declining health as our most important concern, our very lives depending upon a healthy Earth. Our concern for it must come first, because the welfare of the burgeoning mass of humanity demands a healthy planet''*

*''We live on a live planet that can respond to the changes we make, either by cancelling the changes or by cancelling us."*

— James E. Lovelock, *The Revenge of Gaia*

The main message of our book is that we are both much closer to sudden collapse than almost anybody thinks because of planetary organ failure, and with that the wholesale collapse of human societies. The good news is that nature is incredibly resilient and with the right treatment we might still be able to revive our planet's vitality fast. Our focus is entirely on nurturing the living planet back to health and save our societies in the process. If the damage to the biosphere is reversed, the planet will regain its capacity to regulate its own temperature. Ecological restoration can and must be done by everyone everywhere.

**Figure 1:** *Rob de Laet & Dall-E*

## You and I are Part of a Living Planet

Indigenous cultures across the globe, including Native Americans, Aboriginal Australians, Andean peoples, and the Māori of New Zealand, share a profound belief in the Earth as a living, sacred entity. From the Native American concept of "Mother Earth" to the Andean "Pachamama" and the Aboriginal "Dreamtime," these cultures view the planet as a nurturing, spiritual mother figure deeply interconnected with all forms of life. This perspective fosters a strong sense of respect and stewardship for the environment, emphasising harmony and balance with the natural world. These beliefs are central to their cultural identity, spirituality, and environmental practices, underscoring a deep-rooted kinship with the Earth.

The authors have embraced James Lovelock's Gaia Theory, which revolutionises our perception of Earth within the Western body of science. We see the planet as a living, self- regulating entity. This ground breaking concept suggests that our planet functions like a single organism, with its diverse biological processes intricately interconnected and working in unison to maintain and sustain life. Through this lens, Earth's atmosphere, biosphere, oceans, and soil are not just separate entities but components of a larger, living system.

Lovelock shows that the planet has vitality through the interdependence of all species and biomes in the biosphere, highlighting the delicate balance required to sustain life. Like the Indigenous people and the authors of this book we acknowledge that we are part of a living being that needs care and respect. This makes us both offspring and stewards of our planet as we have a clear role to play in preserving this wonderful, living organism and the future generation of humans and other species, with which we have the honour to share this miraculous place in the universe. But, back to the reality of where we are today, because we are running out of time and much work has to be done fast to avert the worst-case scenarios of a dark future to where are now heading.

## How Much Do We Have To Do To Reverse Climate Chaos?

Through a strategic plan, involving large parts of the global population to act locally with place-based solutions, we may still be able to reverse most damage fast. We call on people to organise themselves and focus on the restoration of natural bioregions and watersheds within their domain, all the while cooperating with local communities to bring about rapid improvements. The idea is to involve as many people of the region as possible.

As an appendix we have added a chapter in which we focus on the physical numbers associated with the energetics of evapotranspiration and cloud-forming condensation of water vapour. We show that a tropical humid rainforest, as in the Amazon, per square metre, effects a surface cooling which is more than 100 times greater than the photosynthetic energy required to generate biomass from the carbon extracted from the atmosphere. Consequently, if we could regenerate the forests lost since World War 2 in the tropics and temperate zones, we would offset a good proportion of current global warming. Such expansion of forests would have the increased beneficial effect of reducing the concentration of carbon dioxide in the atmosphere.

## Restoration along Bioregions

If nature were to draw a map of the world, what would it look like? We've grown accustomed to seeing the world divided into countries but there is another way to see, and better understand, the planet we call home. One Earth presents a novel biogeographical framework defined by 185 unique bioregions, which helps reveal the underlying ecological fabric of life that surrounds us.

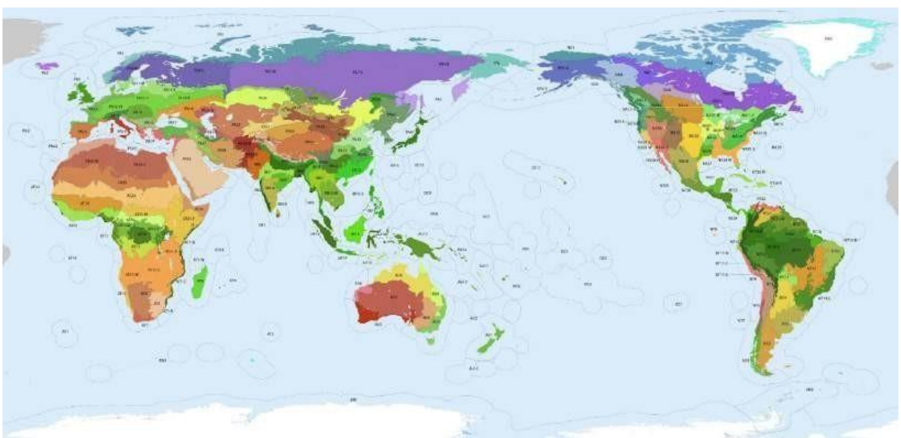


**Figure 2:** *Bioregion map of the World Courtesy One Earth*
https://www.oneearth.org/bioregion

## Ecological Restoration Based on Watersheds

Ecological restoration founded on the concept of watersheds represents a holistic approach to environmental conservation and ecosystem rehabilitation. It revolves around the idea that ecosystems within a given watershed are intricately interconnected, emphasising the need to consider the entire system as opposed to isolated components. Restoration will then contribute simultaneously to the well-being of both the environment and the community.

**Figure 3:** *Water – Photo of Trutta/Shutterstock*

One of the primary advantages of watershed-based restoration efforts is the significant improvement in water quality. By addressing the sources of pollution and runoff within a watershed, restoration projects lead to cleaner and healthier water bodies. This, in turn, has a positive impact on aquatic life and the communities that rely on these water resources for drinking water, recreation, and economic activities. All the diverse ecosystems within the watershed boundaries profit from this improvement, which can start at the level of alpine pastures and may include wetlands, forests, streams, rivers, deltas, coastal lagoons and marine ecosystems.

Watershed restoration projects include plans for biodiversity protection and regeneration, flood control, common water use and common infrastructure. Healthy watersheds are better equipped to face droughts, for instance.

Community engagement is a fundamental aspect of watershed-based restoration. A great example is the Subak system in Bali, Indonesia, where watership councils are formed within communities to protect and manage natural resources, including forests and their biodiversity. The resulting cooperative structure leads to everyone becoming involved in a sense of ownership and stewardship. This engagement not only empowers communities, but also builds a long-term commitment to the sustainable conservation of the watershed. Well managed watersheds improve agricultural and fish production. They also build community cohesion and resilience.

While all people everywhere can become part of a regenerative movement, the damage is too large to leave it just to local forms of citizen action. For global-needed actions we need global organisations and finance.

## The Large Emergency Priorities to Reverse Climate Chaos Fast

This is the list of points we think need to be addressed immediately:

- Avert the **tipping point resulting from die-back of the Amazon rainforest** and strategically reforest the biome to restore the full vigour of the surface-cooling function over the area, by encouraging fast regrowth. This rescue project must include probably more than a million workers getting paid to do the restoration and the finance must come from the whole world, given that all everywhere will be affected if this powerful, natural, cooling organ of the planet dies back.

**Figure 4:** *Healthy Amazon Rainforest – Photo of Theo Tarras/Shutterstock*

- A plan for the **fast revival of ocean biology** including the fertilisation of ocean deserts to sequester carbon, restore the ocean food chain, increase vertical mixing of the water column, increase planetary albedo through increased cloud formation. As this has to happen simultaneously in hundreds of places in the world's coastal marine ecosystems and deep oceans, this must be an internationally coordinated and financed effort.

- A plan to **green the desert areas** from the Thar desert to the Sahara and, through strategic ecosystem regeneration, to draw the Indian monsoon moisture streams all the way to the Mediterranean. In addition, the aim is to increase precipitation over the Third Pole, as the Himalayas and nearby mountain ranges are called because of the thousands of glaciers and snow-clad mountains they hold. Countries from India all the way to Senegal and around the Mediterranean must have a coordinated plan to bring back the atmospheric moisture streams over the areas, rehydrating the lands, regenerating soils and vegetation and cleaning up degraded coastal systems both above and below the water line.

**Figure 5:** *Permaculture food production in India – Photo of Dr. Chandrashekar Biradar*

– Organise the best minds around the world to **reverse polar amplification** by reversing the melt of polar sea ice on both sides of the planet. We may not yet know how to do that but plans are forming, both with nature-based solutions, as well as with some technical interventions.

**Figure 6:** *Sea Ice in the Weddell Sea – Photo of Steve Allen/Shutterstock*

## Global Action

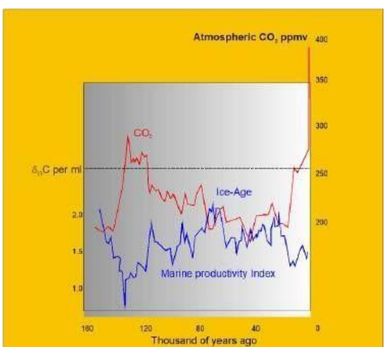
While restoration can and must be done everywhere by everyone, these large projects we describe need the support from powerful organisations like states, armies and large companies. By such means, we can stop the Earth from warming up within decades. Furthermore, such restoration actions will swiftly bring the number of weather extremes to drop significantly.

Here are the global priorities that cannot be done without international cooperation:

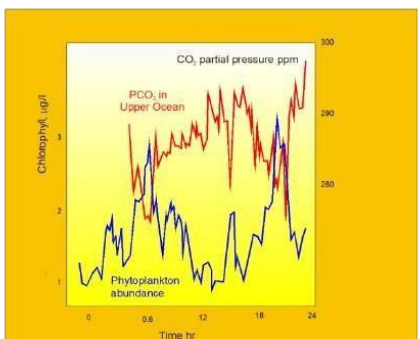
1. To bring finance, information, organisation and tools to the 500 million smallholder families around the world to restore their lands and transition to regenerative agroforestry food production. This will restore the small water cycles, recover degraded soils and substantially increase living biomass. A plan for this has been written. Estimate cost 0.5% of Global GDP per year for a period of twenty years.
2. As such, we invite large networks of organisations such as the Rotaries, WVF (World Veterans Federation), Red Cross, CARE, The Nature Conservancy, Oxfam, WWF, Peace Corps, climate action groups and so on to support communities everywhere to regenerate the ecosystems in their area and improve their economy and well-being.
3. To bring about a programme of ocean and coastal marine ecosystems restoration. Cost of the total programme is in the tens of billions of dollars with almost immediate results.
4. We call for support to assemble in a very short time a Digital Gaia to support all these restoration processes. An outline has been written, almost all parts already exist. Cost to launch first viable product 5 million USD. Let’s build this fast!
5. The planetary restoration project will be financed through several revenue streams from governments, philanthropy, investment programmes, green bonds and carbon credit finance.

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, such efforts 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 square kilometres in the tropical belt from open field to forest, combined with strategically-sited agroforestry, will increase the cooling capacity through the atmospheric water cycle enough to stop the planet from heating up further.

This book, Cooling the Climate, is a proposal to restore the health of our planet fast and with that restore the future of the generations that want to live a happy life on a benign planet that provides enough for everybody's needs (but not everybody's greed!). But first we start with a comprehensive overview of Earth's intricate living systems. The following chapters delve into the science of our living planet, atmosphere, biosphere, climate, and weather, laying a solid foundation for understanding how we can get ourselves out of the climate mess fast.




**Changes in atmospheric carbon dioxide over the past 160,000 years are closely correlated, an inverse relationship, with carbon isotope indicators of plankton productivity. Notice the lag in the correlation at time zero.**




**During a bloom event, fine scale patchiness in upper ocean carbon dioxide is closely correlated with biological activity: underway measurements along a 300 km transect in the North Atlantic**

**Figure 7:** *Atmospheric and Ocean C0₂ values over time – Graphs by Peter Bunyard from the Plymouth Marine Biological Laboratory. The graphs show the role of oceanic phytoplankton, both on a daily basis and over thousands of years in reducing atmospheric $CO_2$.*

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# Chapter 2
# Honouring the Earth's Protective Shield

*"We have a choice. Collective action or collective suicide. It is in our hands."*

Quote from the Secretary General of the UN Antonio Guterres, talking to a group of ministers from 40 countries on 18 July 2022.

**Figure 8:** *Sunrise over the planet showing how thin our protective atmosphere really is. Courtesy: NASA*

The Earth is the only known planet where life thrives, and its complex biosphere has played a critical role in shaping the atmosphere that sustains us. Life has transformed the Earth's atmosphere into a delicate balance of nitrogen, oxygen, water vapour, and greenhouse gases that make human existence possible. This balance, carefully managed by nature over millions of years, has allowed life to flourish. Without the contribution of life to create this atmosphere, human evolution, and survival would have been impossible. We have inherited an atmosphere that not only provides us with breathable air but also protects life on Earth.

## The Protective Role of the Atmosphere

The atmosphere regulates the energy from the Sun, allowing just the right amount to reach Earth for life to thrive. The Sun, a powerful star producing immense energy through nuclear fusion, emits radiation that is harmful to life. Thankfully, the stratosphere acts as a protective shield, filtering out deadly ultraviolet (UV) radiation. Oxygen produced by plants through photosynthesis plays a key role here, as it rises into the stratosphere and interacts with UV-C radiation, the most dangerous form of UV light. This interaction prevents UV-C from reaching Earth's surface, where it could harm life. Additionally, the formation of ozone from this process helps block less harmful but still dangerous UV-B radiation.

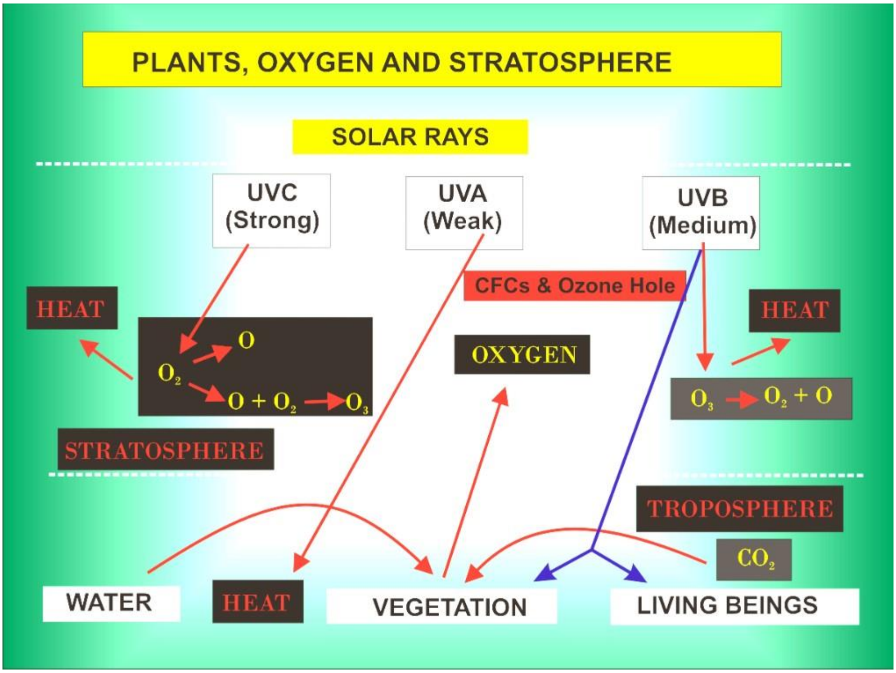


**Figure 9:** *Schematic overview of the interaction between sunlight, the atmosphere and the biosphere. Oxygen generated by plants protects life on the surface from harmful ultraviolet Sun rays – Peter Bunyard*

Another critical component of the atmosphere is the ionosphere, a layer filled with charged particles that interact with Earth's magnetic field. This interaction deflects harmful solar wind and cosmic radiation, protecting life on the planet. The atmosphere also acts as a barrier against space debris like meteors, burning them up before they can reach the surface, although it does not offer complete protection from large meteor impacts. The last major extinction event, which wiped out the dinosaurs 66 million years ago, was caused by a massive meteor strike in what is now the Yucatan Peninsula in Mexico.

## The Impact of Human Activities on the Atmosphere

Human civilization has only been possible because of a stable climate, which began after the Last Ice Age around 12,000 years ago, marking the start of the Holocene epoch. During this time, favourable conditions allowed for the development of agriculture, settlements, and complex societies. However, as we have increasingly exploited natural resources, we have significantly altered the atmosphere, leading to climate change.

The impacts of human activities on the atmosphere are wide-ranging. These include the emission of greenhouse gases like carbon dioxide ($CO_2$) and methane, which trap heat and contribute to global warming. Industrialization has also increased aerosol pollution, and the use of chemicals like chlorofluorocarbons (CFCs) has depleted the ozone layer, further compromising our protection from harmful UV radiation. Land-use changes, particularly deforestation, have disrupted natural water cycles, thus reducing humidity and altering precipitation patterns.

The Earth's temperature regulation depends heavily on water. The movement of water in its various forms—liquid, vapour, and ice—transports solar energy from the surface to the atmosphere, where it is eventually released back into space. This natural cooling process has allowed life to thrive despite the Sun being 30% more powerful than when Earth first formed. However, by altering ecosystems and, thereby, reducing the energy exchange in the atmosphere, humans are disrupting this cooling mechanism, leading to rising surface temperatures and climate instability.

Meanwhile, we must be grateful that life, by means of its metabolism, has put into the atmosphere just the right concentrations of greenhouse gases for capturing and retaining an appropriate amount of the Sun's heat to maintain a stable and liveable climate on Earth.

Without the atmosphere and its greenhouse gases, temperatures would swing from being excessively hot to excessively cold. Quite aside from there being no air to breathe, the planet would hardly be habitable. On the Moon, the temperatures on the side facing the Sun can peak at approximately 127$^0$C (260$^0$ Fahrenheit), while on the lunar night-side temperatures as low as minus 173$^0$C (minus 279$^0$ Fahrenheit) have been observed. And as we saw earlier, if life did not keep the current mix of gases more or less constant, temperatures on Earth would either become lethally high, as on Venus or lethally low as on Mars. We can see how much the atmosphere regulates the Earth’s temperature from the following graph.

Imagine the Earth as a ‘black body’ without an atmosphere and imagine that it is January, when Antarctica is having its summer and the North Pole its winter. The temperature at the North Pole would be -140°C and in Antarctica +40°C. With the current atmosphere, that sharp contrast between the two Poles is smoothed out and the temperature becomes not so different from one to the other, despite the seasonal shifts in exposure to the Sun.

Human civilizations have developed in the last ten thousand years or so during a period of very stable climate just after the Last Ice Age. It is known as the Holocene epoch. During this time, favourable conditions allowed for agriculture, settlement, the rise of complex societies with surplus food production, and with it all the increasing division of labour. One result was the creation of more and more specialised forms of expertise and with that the wonders of technology, which we experience daily throughout the world.

However, our use of natural resources, as if nature was expendable and exploitable, has had severe consequences which we are now beginning to experience with a vengeance and

which have come under the seemingly benign guise of 'climate change'. Climate change now poses significant threats to various aspects of human life. They include risks to food security, to water resources, to all ecosystems, to human health, and to the economy. In essence, changes in temperature, precipitation patterns, and extreme weather events disrupt agriculture, lead to water scarcity, intensify natural disasters, disrupt ecosystems and biodiversity, contribute to the spread of diseases, and have economic implications.

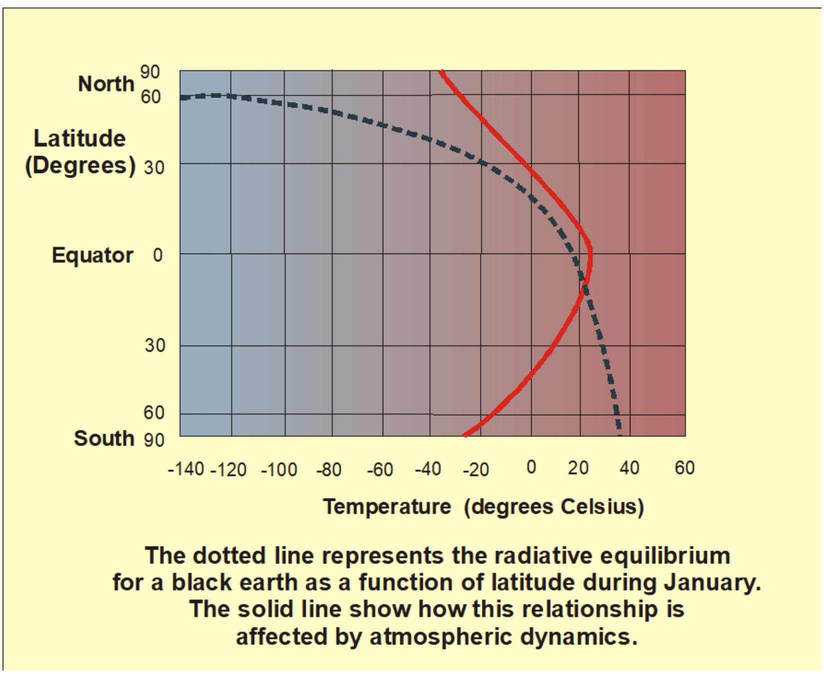


**Figure 10:** *Actual and calculated temperature if there was no atmosphere – Graph Peter Bunyard.*

## How Humans changed the Atmosphere

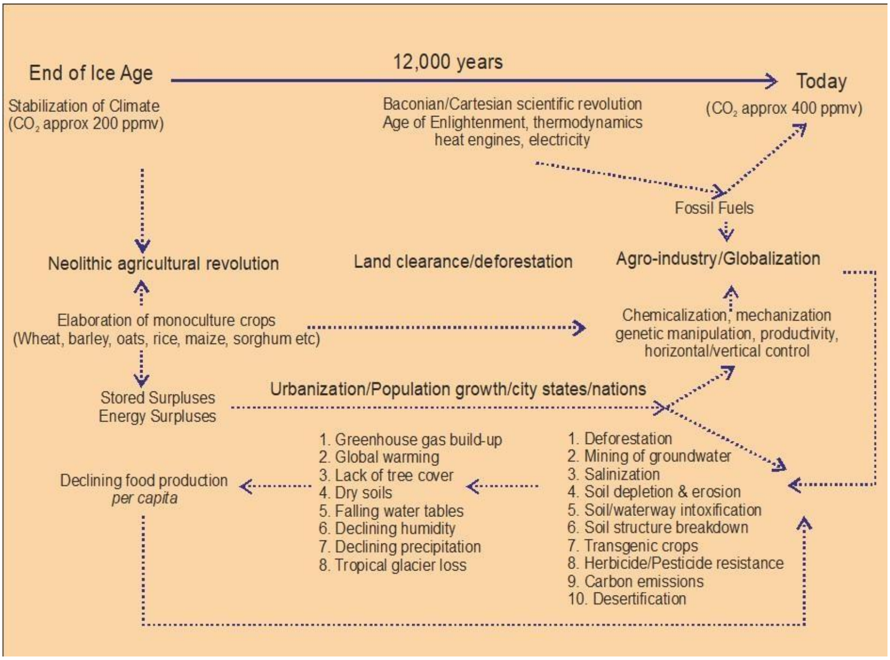


**Figure 11**: *Overview of interacting factors that increasingly triggered the climate chaos, we experience today – Graph Peter Bunyard.*

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. This disruption has happened primarily

because of our destruction of natural ecosystems and, in particular, of forests. An early-on consequence of land-clearances for agriculture and animal husbandry may well have been the desertification of the grasslands and savannas of places like the Gobi, the Arabian Peninsula and the Sahara. In a feedback loop of diminished forests leading to less evapotranspiration and therefore to less clouds and precipitation, natural vegetation had nowhere to go but to retreat under the increasing heat of the Sun and lack of water.

Agricultural practices also led to changes of the water cycle by redirecting and storing water for irrigation, often leading to soil salinization, and altering precipitation patterns through the removal of natural vegetation. In urban settings, the removal of vegetation and the replacement of permeable land with impermeable surfaces, prevented natural water infiltration, increased runoff, and aggravated the local risk of floods. Cities also create "heat islands" with higher temperatures, especially when devoid of vegetation and the cooling effect of evapotranspiration.

**Figure 12:** *Sand and Rocks in the Algerian Sahara – what happened to the vegetation? credit: Shutterstock*

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 vapour. 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 vapour 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. By the disruption of natural water cycles, land-use change has been the most important factor in causing climate chaos and surface temperatures to rise.

## The Biotic Pump – Earth's Irrigation Mechanism

Crucial in this respect is the biotic pump phenomenon, which plays a crucial role in generating atmospheric circulation patterns when the water vapour at saturation point condenses into dense clouds which release their moisture as rain. Over a tropical humid rainforest, the condensation into clouds results in a sharp, instantaneous implosion of air to fill the space left as vapour condenses into liquid water, a volume reduction of more than a thousandfold, from 22.4 thousand cubic centimetres to just 18 cubic centimetres, for each gram molecule of water. That implosive reduction causes surface air to move upwards and that movement, in consequence, draws in the humid surface air from the same latitude ocean. That in essence is the biotic pump and, combined with the recycling of evapotranspired water, the twin processes irrigate the forests deep inland, causing rainfall to be maintained thousands of kilometres from the oceans. In addition, the flow of air provides an extremely important mechanism for tempering the surface winds which flow from the ocean to land, thereby reducing the power and frequency of tropical storms and even hurricanes. Over an area the size of the Amazon Basin, some 7 million square kilometres, and assuming it is still largely forested, the release of the latent heat evaporation energy, as water vapour from evapotranspiration condenses into thick clouds, amounts to as much as the equivalent energy of 14 atomic bombs per second! For further details do go to the appendix chapter.

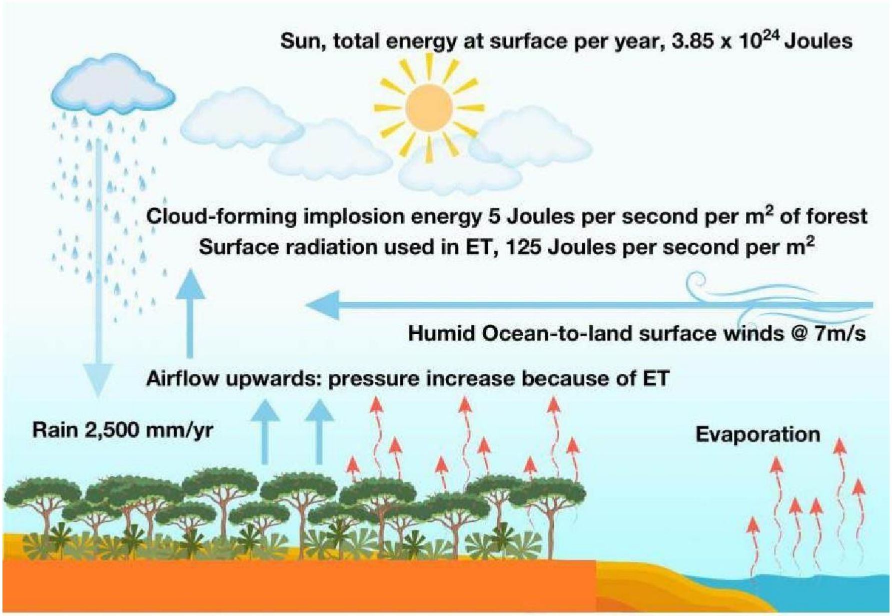


**Figure 13:** *Physics of energy flows creating latent heat, clouds, rain and wind. Latent heat from evapotranspiration (1370 mm/year) takes up 42% of the solar input, i.e. approx. 100 watts of 240 Watts input. The Trade Winds (the Biotic Pump component), is on average 880 mm/year and, therefore, adds 64 watts to the 100. Total Latent heat over the rainforest is 70% of solar input. That latent heat is exported to Space and is a significant means of surface cooling. – Diagram by Andrew Ayres from discussions with Peter Bunyard.*

Since the Industrial Revolution, human activities have profoundly altered the natural environment. The global population has grown to over 8 billion people, with increasing urbanization and material demands driving industrialization. This rapid development has led to the exploitation and destruction of natural ecosystems on a massive scale. In fact, an area larger than China has been deforested, and even larger regions have been degraded. Today, 58% of habitable land (excluding deserts and ice sheets) has been significantly altered by human activities.

The consequences of this widespread environmental destruction are now becoming apparent. Many regions are facing food and water shortages, driven by the degradation of ecosystems and agricultural practices that rely on intensive chemical inputs. The "green revolution," which introduced high-yield crops dependent on fertilizers and pesticides, has temporarily increased food production but has also devastated the health of soils that have supported life for millions of years.

Moreover, as modern industrial food production—based on large-scale monoculture—has replaced smaller, labour-intensive farming systems, natural ecosystems have been destroyed, exacerbating climate change. Large-scale farming of grains, soybeans, and other crops has contributed to regional and global climate chaos by reducing biodiversity and altering water cycles. These activities have made already vulnerable regions more susceptible to extreme weather events, leading to societal collapse in some areas.

Countries like El Salvador, Nicaragua, Venezuela, Somalia, and Yemen have experienced political instability and conflict exacerbated by food and water insecurity, which, in turn, is often linked to environmental degradation. The combination of land-use change, ecosystem destruction, and climate change has triggered refugee crises and destabilized governments, with dire consequences for millions of people.

## Creating the Conditions for the Great Turning

As philosopher Lao Tzu famously said, “If you do not change direction, you might end up where you are heading.” Humanity is at a critical juncture, where the opportunity to avoid the wholesale collapse of global society is rapidly diminishing. However, there is still a small window of time in which we can turn things around. This requires a fundamental shift in how we view and interact with the natural world.

To survive and thrive, we must recognize that we are an integral part of a living planet. Our well-being is directly linked to the health of Earth's ecosystems, just as our physical health depends on the microbial life in our bodies. The planet is a vast, interconnected system that has spent millions of years regulating temperature, moisture, and nutrient cycles to create the conditions for life to flourish. Any further destruction of critical ecosystems—such as forests—will push us past the tipping point, leading to the sudden collapse of societies.

The solution lies in caring for the Earth, including its soils, plant life, and biodiversity. We must reform our lifestyles and food production systems to align with natural processes, which could bring us out of our current crisis within a matter of years, not decades. This would prevent what the UN Secretary-General, António Guterres, has called "our collective suicide." The root causes of climate chaos, food and water insecurity, and environmental degradation are relatively simple to understand, but we must act swiftly to reverse the damage.

## Mobilizing for a Global Movement

The time has come for a global movement to spearhead what we call the *Great Turnaround*. This movement must adopt a planetary perspective and act quickly to prevent the irreversible collapse of human societies. Fortunately, we have the tools to make this happen. The internet and social media have created a global web of collective knowledge and interaction, which can be harnessed to spread awareness and inspire action on a massive scale.

In addition, some of the world's largest investors, such as pension funds and sovereign wealth funds, have recognized that their assets are at risk due to climate change. As climate instability threatens entire regions, the financial sector is beginning to understand the need for investment in regenerative projects. A new asset class focused on restoring the planet could become the largest investment opportunity in history, driving large-scale environmental recovery.

Artificial intelligence (AI) can also play a role in accelerating project design and management, helping local communities develop climate-resilient landscape restoration plans. These plans would be tailored to the specific needs of each bioregion, creating well-being for people in harmony with nature.

Ultimately, to succeed, we must capture the hearts and minds of younger generations, who are currently witnessing the destruction of their future. A global movement for regeneration, fuelled by the passion and creativity of youth, can help reverse the damage and create a more sustainable and resilient world.

## The Story of a New World of Simple Abundance

Large human movements have been driven by powerful stories, with some of the most impactful ones derived from religious sources. Such stories were successful because they promised a better world and a radical improvement of living conditions. Let's create a new powerful story where we trust the intelligence of the Earth, of Nature and embrace and stimulate her revival for the emergence of a liveable future with simple abundance for all. The new story describes an exciting world which is in peace with itself, takes care of all life and is based on great cultural virtues such as justice, kindness, honesty, generosity, humility, wisdom and fun. Let us come together and tell that new story that is created by vibrant, young multi-coloured, multi-cultured people celebrating the gift of life. Together we have the power to heal our beautiful living but wounded planet and with that create that beautiful world for all life to thrive for many generations to come.

## Through the Eye of the Needle

This is the famous moment where we have to get through the eye of the needle to overcome our current existential challenge. The expression comes from the Bible, where a wealthy man asks Jesus what he must do to inherit eternal life. Jesus tells him to sell his possessions and give the money to the poor. In that vein, we will need to redirect the unevenlyaccumulated wealth, held by few, to regenerate our planet fast and invest in the habitable world of tomorrow, based on sustainability, circularity, vibrant ecosystems while taking care of the basic needs of all.

**Figure 14:** *Syntropic farming was developed in Brazil, where there are now large-scale profitable multi-crop plantations. (courtesy: Life in Syntropy)*

Traditional Indigenous cultures have much to teach us with respect to societies and communities living sustainably within the capacity of their local environment to provide them with the bulk of their needs. In those cultures, as exemplified by traditional Amazonian peoples, communal well-being is prioritised over the individual accumulation of wealth and the wealthiest person is he or she who is most generous, distributing the abundance of what they have to other members of the community. The economy of such communities is based on the notion of reciprocity and exchange, not only within their own communities but on dealings with other, even ethnically distinct communities. And, what is critical for the survival of such communities, is that they apply the same principles of reciprocity and exchange with the natural world around them. For example, the Tanimuca of the Colombian Amazon believe that the Sun, passing overhead, bathes the forest and all its creatures with an element which can be translated as 'thought/wisdom', and which is shared right across the biological spectrum. Therefore, it is the duty of the community, when hunting and gathering or when creating their slash and burn gardens (chagras) to maintain and respect the equilibrium which the Sun has provided. Such peoples are ecologists by culture and being so is part of their cosmology.

**Figure 15:** *A traditional house called a maloca, built by members of an isolated, semi-nomadic group, is pictured in 2011 near the Jandiatuba River in western Brazil. (CNS photo/Peetsa/Acervo CTI, courtesy ORPIO)*

Greed in our industrialised and materialist culture is currently one of the great causes of the destruction of our living planet. Given the urgency of what is needed to restore equilibrium and balance to our planet, we should hope for those with excessive wealth to help fund the fast transition of our societies and help regenerate our world with future generations in mind. We will soon realise that the imagination of humans and the lifeforce in new generations can overcome our current challenges. Once we wake up out of our bad dream that the future is impossible to save, our agency to act will come about and we can heed the call of the United Nations leader, Antonio Guterres, and take the collective action to avert collective suicide and open the windows to that beautiful future our hearts know is possible. It will be a great time to live and to be part of the most remarkable transformation humans have so far achieved on our short journey as a young, juvenile but promising species, a journey that has only just begun.

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# Chapter 3
# What is Climate, Really?

Our climate is changing, but climate, by its very nature, is always changing, and it cannot be otherwise. The Sun as a main sequence star is now some 30 per cent brighter and more luminous than it was when the Earth formed some 4,500 million years ago on account of the thermonuclear reaction speeding up, all of which would mean a warmer Earth, were that the sole factor involved. In addition, the Earth's orbit around the Sun never precisely repeats its rotation and sometimes the Earth is nearer, and at others further away than would be delineated by a perfectly circular orbit. That means that different parts of the planet, in the north and south, get more or less sunlight during their respective winters and summers than they would if the orbit was a perfect one.

Nearly one century ago, the Serbian mathematician, Malankovitch, suggested that such variations in the Earth's orbit were responsible for triggering the ice ages and interglacial periods to which the planet has been subjected over the past few million years. The evidence appears to suggest that with regard to past episodes he may well have been right, but again nothing ever remains the same and the impact of human beings on the Earth is distorting any such tendencies.

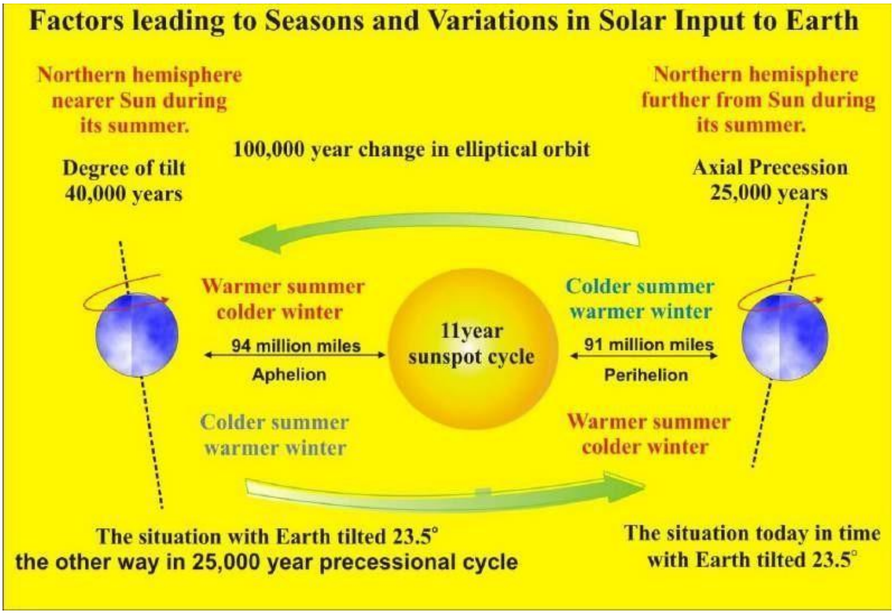



**Figure 16:** *Solar Input changes of seasons and the Milankovitch cycles changing weather and climate – Graph by Peter Bunyard*

## Distribution of Solar Energy

Sunlight is the main driver of climatic processes on Earth, providing light and heat which, in passing down to the surface of the Earth, generates currents in the oceans and movements of the air in the atmosphere and, most important, causes water to evaporate from the oceans such that clouds form and bring rain to the continents. The Sun also provides the energy in the form of light for photosynthesis which enables plants and algae to synthesise carbohydrates, such as glucose, from carbon dioxide and water. The resulting, energy-rich carbon-based building blocks can then be used in the synthesis of proteins and other compounds essential in the metabolism of living cells. As we shall see, life has long played a significant part in regulating the temperature of the Earth's surface and therefore has helped form what is today's climate. We can truly say that life and the Earth have co- evolved over the past 4,000 million years, taking into account cataclysmic events, such as the Earth being struck by an asteroid, like the one of some 66 million years ago, which brought about the extinction of the dinosaurs.

In addition to accumulative changes in the Sun over its history as a star, how much energy gets sent out to space at any one moment of time depends on variations in solar activity, such as during sunspot cycles. Such cycles have a periodicity of around 11 years, with sunspots appearing and then vanishing. Some four centuries ago, in the early 17th century, the famous Italian scientist, Galileo Galilei, was able to observe sunspots, just as had Chinese astronomers many centuries before; we now know that when sunspots become more numerous the amount of energy reaching the Earth goes up, perhaps by as much as 0.1% and vice versa, declines during periods of low sunspot activity, as happened during the Mini Ice Age of the 18th century. Then, Europe froze over during its winters, as is shown in paintings of the river Thames, with people skating happily over the surface.

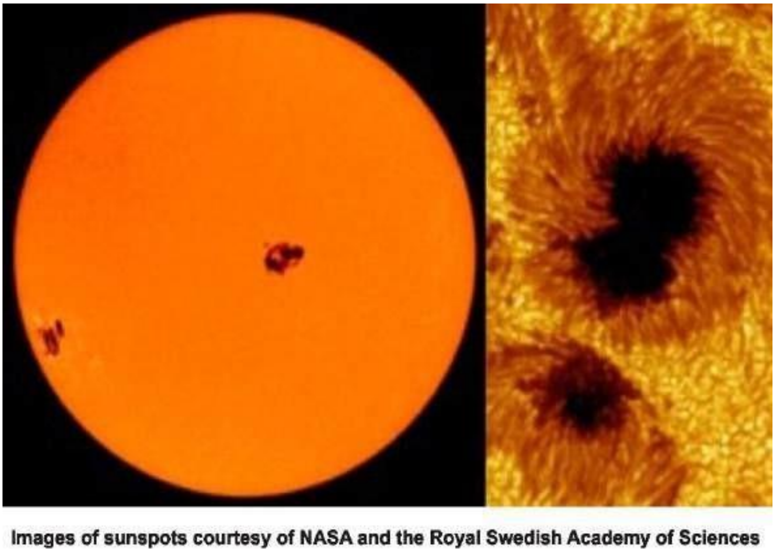



**Figure 17:** *Sunspots*

In reality, there was an additional factor, all to do with the regeneration of forests over an area of 55 million hectares. That regeneration was a consequence of the European invasion of the Americas which brought death and destruction on a massive scale to the indigenous populations. The abandoned lands grew back as forest, the net result being a reduction in greenhouse gases as the forests laid down biomass. In addition to the reduction in atmospheric carbon dioxide, the forest increased the rate of evapotranspiration significantly above that pertaining when the Europeans first arrived. The enhanced evapotranspiration from the spread of forests led to an average surface cooling of as much as $1^0$C. (Koch, Alexander., Brierly, Chris., Maslin, Mark M., Lewis, Simon. L. *Earth system impacts of the European arrival and Great Dying in the Americas after 1492*. Quaternary Science Reviews Volume 207, 1 March 2019, Pages 13-36.)

The picture below, showing St Paul's Cathedral in London, as it was before the Great Fire of 1666, shows us the consequence of even a small change in surface temperature.

**Figure 18:** *Winter during the ''Little Ice Age'' – photo credit Museum of London*

We well know the importance of surface colour as to whether more or less heat is retained under the midday Sun at the height of the summer. Try walking barefoot across a beach with dark volcanic sands when the Sun is beating down; it can be a truly painful experience. Compare that with sitting on a light coloured, or white painted surface. In fact, changes in the reflectivity of the Earth's surface – in the Earth's *albedo* – illustrate full well the principle of *feedback* in accelerating or damping down change. When the ice caps develop, both thickening and spreading, more of the Sun's rays are reflected back to Space and the general effect is for the temperature to remain low and for the ice and snow to spread ever more towards the lower latitudes, as indeed happened during the last glacial maximum some 40,000 years ago. That spreading and chilling of the surface temperature will reach some limit where the Sun's rays over those lower latitudes will be sufficiently strong to melt the ice as fast as it forms.

A slight change in the power of the Sun to melt the ice could mean that the ice melts faster than it can reform and instead of a reflective surface, the one which is exposed, be it dark rock or the open sea, now absorbs rather than reflects such that the warming and melting spreads back again towards the polar region. With regard to freezing and thawing cycles, the type of vegetation in the boreal, northern regions, can provide its own feedback and accelerate or restrain climate change. Pine trees, with their dark needles and Christmas tree shape, can grow up to the Arctic Circle, but from there northwards to the North Pole, the long, dark winter months and the low temperatures, prevent their colonisation of the frozen wastelands. However, such trees, by their conical shape, are ideally formed for shedding snow. Thus, in springtime, when the first rays of the Sun rise up over the horizon, the conifers expose their dark green needles, capturing certain wavelengths for photosynthesis and simultaneously warming up as light is absorbed and converted to heat. That way, a boreal forest of conifers will actually warm up its environment, the benefits being faster growth than would otherwise be the case and gives such trees an advantage compared to leaf-shedding deciduous trees, like birch, trembling aspen and poplar. Contrast that with the climate conditions beyond where the forest can grow. There, not only will the snow stay longer, having no conifers to warm up their local environment, but we will find permafrost, where the ground just below the surface is permanently frozen.

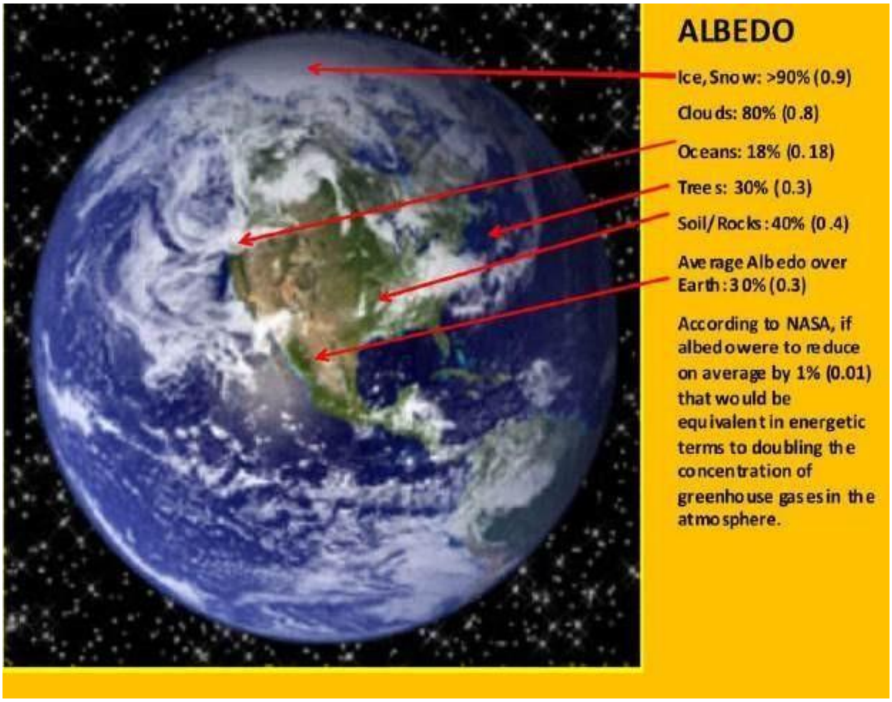



**Figure 19:** *Different Albedo values on the planet – Graphic: Peter Bunyard*

*Albedo* is an important factor in determining the Earth's surface temperature and, according to NASA (National Aeronautics and Space Administration of the United States) if albedo were to reduce on average by 1% (0.01) that would be equivalent in energetic terms to doubling the concentration of greenhouse gases in the atmosphere and therefore adding several degrees centigrade to the surface temperature of the Earth. Could that happen? In some respects, the process is already happening, for as glaciers melt and sea ice disappears what is exposed, bare rock and ocean, for example, have much lower albedos than the ice which was there before. A surface which reflects most of the sunlight, sending the rays back towards space, is considered to have a high *albedo,* while one which absorbs sunlight has a low *albedo*, the *albedo* being measured on a scale of 0 to 1, or 0% to 100%. For instance, ice, snow and dense clouds, all have high albedos, while the open oceans, vegetation and bare rock have a low albedo.

**Figure 20:** *High Albedo snow cover in majestic winter landscape – photo Andrew Mayovskyy/Shutterstock*

## Earth's Rotation

As Figure 16 shows, the Earth's orbit around the Sun is not constant, but varies from year to year in a long-term cycle of some 100,000 years, which takes it from being nearly circular to one that is more elliptical. The Earth's axis is also tilted from the perpendicular and, because the planet spins rather like a spinning top, it shifts from side to side every 25,000 years or so. Consequently, each hemisphere in turn is more exposed to the Sun during its summer or winter months simply because of the shift in orbit. When the orbit takes the Earth closest to the Sun, the facing hemisphere, enjoying its summer months, may receive as much as 3% more solar energy compared to the other hemisphere during its summer because it faces the Sun when the Earth is furthest away. Such shifts in the Earth's orbit are known as *Milankovitch Wobbles*, named after the Serbian mathematician who first described such distortions in the Earth's orbit, and who suggested that the 100,000 year-cycle might coincide with times of ice-ages.

## Gaseous Composition of the Atmosphere

The composition of the atmosphere is made up of gases which, with rare exception, are all part of life's metabolism. Some of those gases, carbon dioxide, methane and nitrous oxide, as well as others, like the CFCs – chlorofluorocarbons – which we have manufactured, have properties which cause the infrared waves of heat to be trapped at the Earth's surface, rather than easily passing back into space. That way, the Earth's surface warms up, as it happens by an average increase in temperature of some 34°C, taking the surface temperature to an average 16°C instead of a chilling -18°C. Remember that those are average temperatures over the planet's surface and therefore they incorporate the extremes of temperature which we associate with the polar and tropical regions.

## Nitrogen in the Atmosphere

Nitrogen ($N_2$) makes up about 78% of the Earth's atmosphere and is essential for life, as it is a key component in amino acids, proteins, DNA, and RNA. Fortunately, most nitrogen remains in the atmosphere rather than being lost to the oceans. Nitrogen-fixing bacteria, such as those found in the root nodules of leguminous plants like beans and peas, capture nitrogen from the air, turning it into forms that living organisms can use. This process requires energy, and the bacteria operate in low-oxygen environments. To support them, the host plants produce a form of haemoglobin that binds to oxygen, giving the root nodules their characteristic red colour.

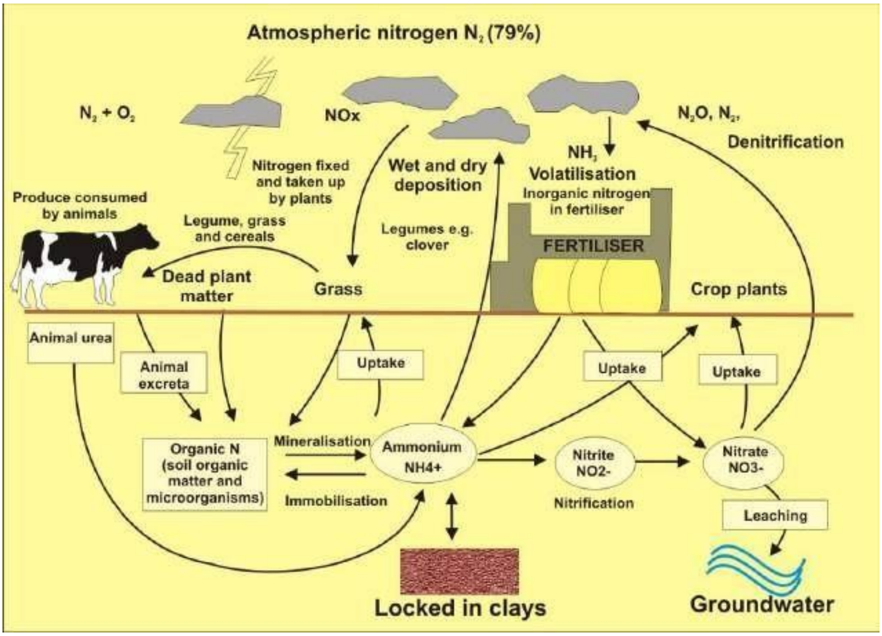



**Figure 21:** *Nitrogen cycle. Graph Peter Bunyard.*

When living cells decompose, some nitrogen is converted into nitrous oxide ($N_2O$), a greenhouse gas 300 times more potent than carbon dioxide. However, the concentration of $N_2O$ in the atmosphere is much lower than $CO_2$, accounting for only about 9% of greenhouse gas emissions, while $CO_2$ makes up 72% and methane 18%.

## Oxygen and Its Role in the Atmosphere

$O_2$ is the next most abundant gas in the atmosphere. Over time the content of the atmosphere has changed and oxygen levels have varied greatly during different periods of the Earth's history. We must attribute the current oxygen concentration of 21% in the atmosphere to Life and in particular to photosynthesis which, through the energy derived from the Sun, results in carbohydrates being formed from carbon dioxide and water ($6CO_2 + 6H_2O = 6O_2 + C_6H_{12}O_6$). Oxygen, in common with nitrogen, is not a greenhouse gas.

## Methane: A Potent Greenhouse Gas

Methane ($CH_4$) is produced primarily by methanogenic bacteria, which thrive in low-oxygen environments like waterlogged soils, swamps, rice paddies, and the digestive tracts of ruminants such as cattle. These bacteria remove oxygen from carbon dioxide, producing methane in the process. Methane is the next most significant greenhouse gas after water vapour and carbon dioxide.

Methane levels in the atmosphere have more than doubled since the pre-industrial era, rising from 0.8 parts per million by volume (ppmv) to about 1.9 ppmv today. Methane's warming effect is significant, and its concentration tends to rise during warmer periods and drop during colder spells. Methane is broken down in the atmosphere by hydroxyl radicals, ($^{-}OH$), which are produced when ultraviolet light from the Sun splits ozone molecules. Climatologists ascribe 60% of methane emissions — close to 300 million tonnes — to man-made sources. Currently some 60 million tonnes a year of methane are accumulating in the atmosphere. Large quantities of methane remain trapped under permafrost in boreal regions and within methane hydrates on the edges of continental shelves. As the Earth warms and permafrost melts, these stores could release vast amounts of methane, potentially triggering a runaway feedback loop that would accelerate global warming. This is particularly concerning in places like Siberia, which is warming faster than other regions.

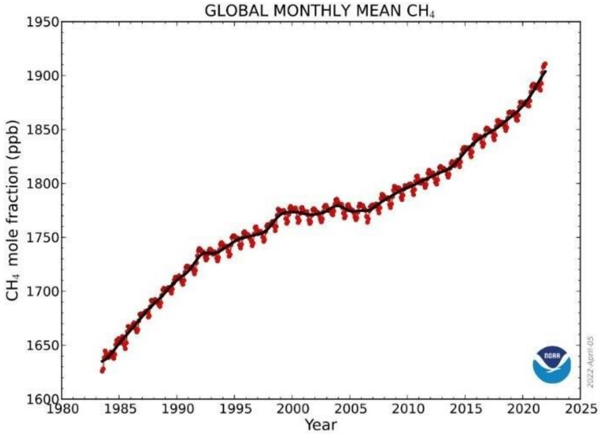



**Figure 22**: *Atmospheric Methane increase over time in parts per billion – courtesy NOAA*

## The Global Warming Potential of Greenhouse Gases

Each greenhouse gas makes its own particular contribution to global warming, which it continues to do until washed out of the atmosphere by rain, absorbed into soils and oceans or broken down through chemical interactions, some powered by sunlight. Sometimes those interactions lead to the production of other greenhouse gases — for instance, methane oxidises to carbon dioxide and water. Meanwhile, a gas, like a CFC, may be present in the atmosphere in very low quantities, but still have a significant effect. Climatologists therefore invoke the idea of *Global Warming Potentials* in which the impact of emitting 1 kg of a gas over a stretch of time, such as 100 years, is compared with that of carbon dioxide. The global warming potential therefore takes into account the disappearance of the gas from the atmosphere over time. Global warming potentials are likely to increase in the future when carbon dioxide builds up in the atmosphere. The increase comes because of saturation effects. Thus, relative to carbon dioxide the effects of other greenhouse gases will become proportionately greater.

## Global Warming Potentials

(The warming effect of an emission of 1 kg of each gas relative to that of carbon dioxide)

| | 20 YEARS | 100 YEARS | 500 YEARS |
|---|---|---|---|
| Carbon dioxide | 1 | 1 | 1 |
| Methane | 63 | 21 | 9 |
| Nitrous Oxide | 270 | 290 | 190 |
| CFC-11 | 4500 | 3500 | 1500 |
| CFC-12 | 7100 | 7300 | 4500 |
| HCFC-22 | 4100 | 1500 | 510 |

## Gaia Thesis and Oxygen

In 1969, James Lovelock came up with a hypothesis in which he proposed that life in all its forms and variations acted with its immediate surroundings to generate optimum conditions for life to flourish. He named the hypothesis *Gaia* after the Greek Goddess of the Earth, and we use that name when we talk of *Geo*-graphy or *Geo*-logy or *Geo*-physics. Now, a half-century later, many have investigated the tenets of the original hypothesis and have upgraded it to be the *Gaia Thesis*.

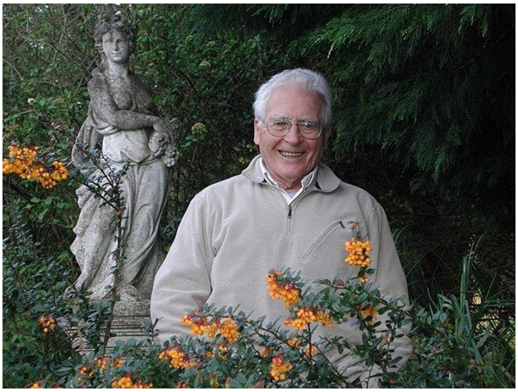


**Figure 23:** *James Lovelock in 2005 – scientist and author of the Gaia hypothesis next to the Earth Goddess, Gaia – Photo Courtesy Bruno Comby under Creative Commons license.*

In the early 1970s, Lovelock teamed up with Lynn Margulis, a biologist renowned for her studies of symbiotic relationships between species and for the phenomenon of *endosymbiosis* in which ancient bacteria had incorporated themselves into the nucleated cells of *higher organisms.* We now know that the mitochondria, essential for respiratory processes in cells and the chloroplasts, which are the sites of photosynthesis in the stomata of leaves, were originally free-living bacteria. Lovelock and Margulis have suggested that the production of oxygen by cyanobacteria as long ago as 3,800 million years (3.8 GA) may have prevented the loss of water from the Earth as the result of the oxygen reacting with hydrogen which would otherwise have percolated upwards from the Earth' surface and escaped into space. Certainly, Venus, with a surface temperature on average close to 500$^0$C has lost virtually all its water, and it is debated how much water still remains on Mars, where the thin atmosphere, mostly composed of carbon dioxide, gives the planet an average surface temperature of -60$^0$C.

**Figure 24:** *Stromatolites are rock-like structures built by cyanobacteria colonies - Photo Ikonya/Shutterstock*

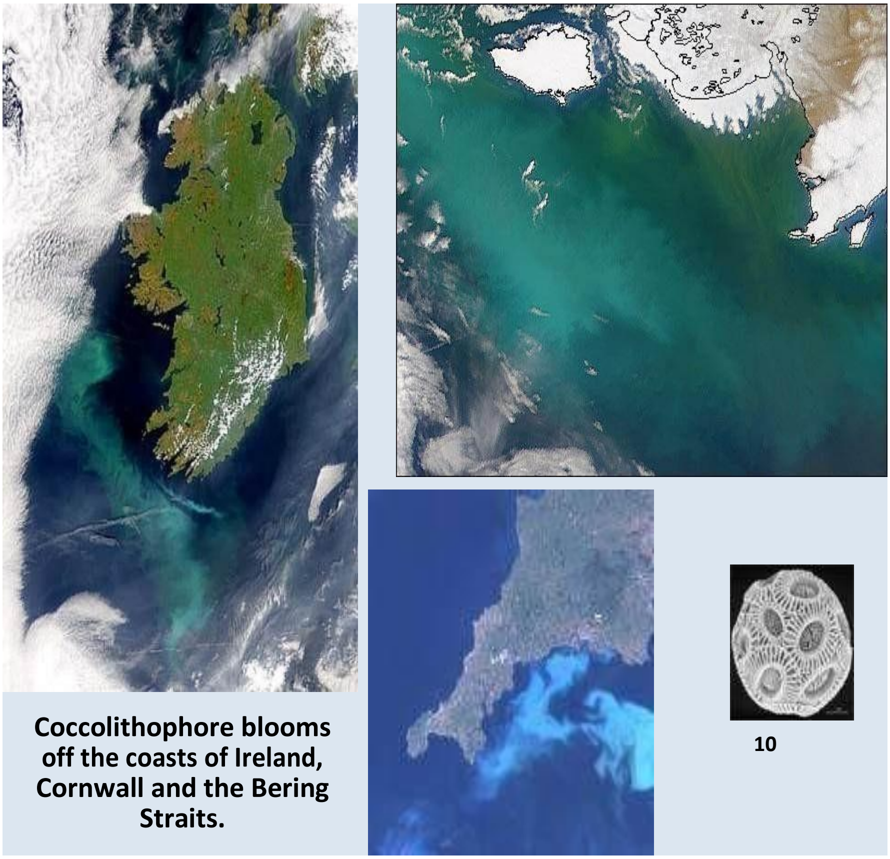
Lovelock observed that Earth's atmosphere, with its unique mix of nitrogen (78%), oxygen (21%), and small amounts of carbon dioxide and methane, is unlike the atmospheres of Venus and Mars. Indeed, once the atmospheric gas spectra of both Venus and Mars became known, with both planets having atmospheres composed predominantly of carbon dioxide and just trace amounts of oxygen, with little to no nitrogen, that finding confirmed Lovelock's scepticism on scientific grounds, that NASA would find life on Mars. In effect, the atmospheres of Mars and Venus were close to a chemical equilibrium, which would have come about over time as the gases interacted with each other through the processes of oxidation and reduction as well as escapes of hydrogen into space from the photolytic decomposition of water. Meanwhile, the presence of 0.003% of the reducing gas methane, whereas Mars and Venus had none, indicated that the Earth's atmosphere was orders of magnitude away from chemical equilibrium and, according to Lovelock, kept in that state by living processes, such as by the activities of bacterial methanogens. He also surmised that methane in the atmosphere helped to regulate oxygen levels, atmospheric oxygen itself being a product of biotic photosynthesis.

With the evolution of eukaryotes from prokaryotes, metabolic activities, such as photosynthesis and consequently respiration, could be vastly scaled-up. The evolution of the angiosperm trees with their vascularised leaves and stems, and the high rates of transpiration and photosynthesis, is a good example of the scaling up that resulted from cyanobacteria becoming incorporated, with their own separate DNA, by symbiogenesis into the eukaryotic cells of plants to form the chloroplasts. The spread of forests, the evolution of grasses and the evolution of phytoplankton led simultaneously to oxygen levels rising to their current value of 21% and the deposition of carbon dioxide as fossil fuels and, associated with calcium, as deposits of carbonate.

In developing the Gaia Hypothesis, Lovelock realised that for life to be responsible for generating the current composition of the atmosphere, its metabolic activities would have to be global in extent. The handprint of life was in the atmosphere. Lovelock then asked what the Earth's atmosphere would be like were the planet never to have had life? If similar processes of outgassing, as has occurred during the past 4.5 thousand million years on Venus and Mars, had taken place on an

Earth-without-life, then the composition of the atmosphere would be 98% carbon dioxide, a trace of oxygen, no methane and an atmospheric pressure 60 times that current today. The average surface temperature would be a life-killing $240^0$C compared to the actual $15^0$C of today's Earth.

Lovelock also explored how life influences surface temperatures. He developed the CLAW Hypothesis with other researchers, suggesting that a compound called dimethyl sulphide (DMS), released by blooms of marine phytoplankton, such as the single-celled coccolithophores, helps regulate climate. DMS converts into cloud-forming particles, which increase cloud cover and cool the surface by reflecting sunlight. This creates a negative feedback loop: as ocean temperatures warm, DMS emissions increase, forming more clouds and cooling the waters below. However, there's a limit to this process. Phytoplankton thrive in cooler waters, and when surface temperatures rise above 12°C, a barrier (thermocline) forms, preventing nutrient upwellings that support phytoplankton growth. As a result, warmer waters reduce cloud formation, leading to a positive feedback loop where warming accelerates. Overall, the Gaia Thesis highlights how life itself plays a crucial role in maintaining Earth's climate and atmospheric balance, ensuring conditions remain suitable for the continuation of life.




**Coccolithophore blooms off the coasts of Ireland, Cornwall and the Bering Straits.**

**Figure 25:** *images of coccolithophore blooms and the amazing design of their skeletons – Peter Bunyard*

## The Atmospheric Water Cycle and the Role of Bioaerosols

The heart of the Earth's climate system is formed by the atmospheric water cycle, which governs weather patterns, precipitation, and long-term ecosystem stability through which it processes incoming sunlight. Water vapour is the dominant greenhouse gas, with $CO_2$ an important second one. While increasing $CO_2$ causes the atmosphere to retain more water vapour, bioaerosols actively lower vapour concentrations by promoting re-condensation and cloud formation, which together cool the surface, facilitate precipitation and, as have pointed out throughout this book, allow for latent heat export out to Space when water vapour condenses at cloud level. In this way, bioaerosols play an important role in regulating the climate by counteracting the greenhouse effect amplified by the $CO_2$-driven increase in the concentration of water vapour.

We know from the Clausius-Clapeyron equation (see Fig. 64 in the Annex) that warmer air holds exponentially more water vapour to the point of saturation, than colder air. In effect, for every 1°C rise in temperature, the atmosphere can hold about 5% on average more water vapour. And since water vapour is responsible for most of the greenhouse effect, more warming, which may initially come from human-derived greenhouse gas emissions, results in the potential for further warming in a self-reinforcing non-linear feedback loop.

Thus, as we have added $CO_2$ to the atmosphere, we have caused the surface air to hold back more heat which, in turn, has allowed more water vaporisation, thus amplifying the total greenhouse effect of both water vapour and $CO_2$. Simultaneously, we have degraded and destroyed those ecosystems which generated the self-same bioaerosols that naturally would have stimulated cloud-formation and, with that, water vapour condensation. Consequently, we have not only enhanced global warming, but we have downgraded the processes which would have led to surface cooling, namely through latent heat release and irradiation to Space.

## The Importance of Bioaerosols for Precipitation and Cooling

Recently, much attention has been focused on anthropogenic aerosols from industry and shipping, while the vital role of natural bioaerosols in climate processes has been largely ignored in climate science. In fact, nature, through the evolution of plant species and phytoplankton, has been generating processes for over a hundred million years to regulate the small water-cycles which permit life to flourish far inland from the oceanic source of water. The production of a range of bioaerosols has played a significant part in surface cooling and the spread of life deep into the continental interior. If it had not been for such evolution, the

Earth’s land surface would have looked more like Mars or, at best, the Sahara with only some biological activity where the land touches the sea!

## Water, the Energy Regulator

Water's ability to change states - between liquid, vapour, and ice - enables it to function both as a coolant and as a greenhouse gas, depending on its phase. This is also the main reason why it is so difficult to model in the climate models, as it shapeshifts all the time and jumps from coolant to heating substance depending on time, place and state. As we have discussed, when water evaporates, it absorbs heat from its surroundings, cooling the environment in the process. This latent heat, having excited water molecules sufficiently to turn them into a gas, is carried up into the atmosphere where it can be released during condensation. Bioaerosols have the characteristic and indeed advantage that they bring about vapour-condensation at higher temperatures and lower humidity levels, and therefore well before the conditions for water vapour saturation have been reached, presumably at considerably higher altitudes. Hence, without aerosols, the condensation process would require much cooler temperatures and greater vapour concentrations, all of which would lead to lower rates of precipitation and more time in the atmosphere for water vapour to act as a greenhouse gas and cause more heat to be trapped at the surface for longer.

## The Nature of bioaerosols

Bioaerosols are tiny particles of biological origin such as bacteria, fungi, pollen, and plant debris. They are also biologically-generated volatile substances, like isoprenes, terpenes and dimethyl sulphide. On land, they are emitted into the air by plants together with the water that is evaporated through the stomata of plant leaves during photosynthesis. These particles provide ‘’landing platforms’’ or ‘’cloud condensation nuclei’’ (CCN).

All healthy ecosystems contribute to cooling, cloud formation, and precipitation through their interactions with water and the atmosphere. From coral reefs and phytoplankton, which release aerosols that help seed clouds, to grasslands that produce bioaerosols and facilitate moisture cycling, nature has evolved complex systems to regulate temperature and create rainfall. Rainforests are the champions of this process. With their vast biodiversity and dense canopy, rainforests generate immense quantities of bioaerosols, recycle moisture through evapotranspiration, and drive large-scale cloud formation and precipitation. This makes them critical players in maintaining regional and even global weather patterns, providing the most efficient natural system for cooling and generating rain. While much research is needed, there are even indications that healthy forests orchestrate their rainfall patterns according to their needs!

## Bioaerosols and Ecosystem Health

The production and distribution of bioaerosols are closely tied to ecosystem health. Forests, especially, act as significant bioaerosol factories:

– Tropical rainforests emit vast amounts of fungal spores and bacteria, in addition to terpenes and other volatile bioaerosols, all of which serve as effective cloud condensation nuclei.

– Boreal forests release organic compounds like terpenes that transform into aerosols, aiding cloud formation.

– Grasslands and agricultural regions contribute pollen and plant particles, influencing local weather patterns and supporting bioprecipitation.

– Marine ecosystems, like seagrass, coral reefs and phytoplankton, release organic compounds like dimethyl sulfide (DMS), which transform into aerosols in the atmosphere.

In conclusion, healthy, biodiverse ecosystems produce a wide variety of bioaerosols, which are essential for sustaining stable weather patterns and consistent rainfall. Restoring and protecting these ecosystems ensures that bioaerosol levels remain sufficient to support the natural precipitation processes that keep climates balanced and ecosystems thriving. Instead of allowing water vapour to accumulate excessively in the atmosphere, which can lead to intense and sudden downpours, bioaerosols promote early condensation, releasing moisture more evenly and regularly. Healthy ecosystems therefore also produce more gentle rains, spread out over more time, giving the water time to be absorbed into soils and aquifers, promoting healthy soil biology, again nurturing ecosystem health and with that more vigour and resilience.

## Strategic Approaches to Enhancing Bioprecipitation

Given the vital role bioaerosols play in bioprecipitation, strategic efforts to enhance this natural process are essential for climate repair. By far the most effective approach is ecosystem restoration. By preserving and restoring biodiverse forests, grasslands, and other natural landscapes, we can maintain the natural sources of bioaerosols that seed clouds and bring rain. Reforestation, wetland protection, and the promotion of agroforestry practices that integrate trees into agricultural systems are practical steps toward this goal. By understanding and harnessing the power of bioaerosols, we can take meaningful steps toward climate repair, ensuring a more stable and sustainable atmospheric water cycle for future generations.

# Chapter 4
# The Magic of Photosynthesis, and Our Future

Life's smartest invention so far has been photosynthesis, in which chlorophyll molecules shaped like antennae, their magnesium atoms suspended in space and fine-tuned by the tweaking of the enclosing protein structure, are able to capture photons and stream them down to activation centres. There, a concerted effort by between 8-12 photons of the right wavelengths, brings about the necessary cascade of electrons that leads to the splitting of water. One amazing finding is that the numbers of aligned chlorophyll molecules in a leaf — more than trillion for every square centimetre — are at the right density to pick up most of the right wavelength photons of daylight hours.

## How to Catch a Falling Electron

The ultimate source of all our energy and negative entropy or syntropy is the radiation from the sun. When a photon interacts with a material particle on our globe it lifts one electron from an electron pair to a higher level. This excited state as a rule has but a short lifetime and the electron drops back $10^{-7}$ to $10^{-8}$ seconds to the ground state giving off its excess energy in one way or another. Life has learned to catch the electron in the excited state, and let it drop back to the ground state while utilising its excess energy for life processes. The net result is that of $240W/m^2$ of solar energy received on average at the Earth's surface barely $0.7W/m^2$ worth of energy gets through for the production of new biomass.

The fundamental difference between man-made machines and life is the exquisite efficiency with which energy is employed in living processes. The eye, for example, can detect a single photon and through a cascade of molecular transformations, generate an electrical impulse to the brain that may be one million times more powerful than the original signal — and all in no more than one-hundredth of a second. If life were as inefficient as our emulations of its processes, then cells would soon overheat and coagulate, like a boiled egg. The extraordinary efficiency displayed in living organisms distinguishes them from man-made machines.

Energy in the living cell is further held and partitioned by life through the intricate web of different interacting forms. Primary producers — bacteria and plants — are consumed by a range of different grazers and herbivores that themselves fall victim to predators. Finally, in death, virtually all life's forms decay and decompose, helped on their way by fungi, bacteria and even scavenging creatures such as hyenas and vultures. Overall, the more varied and diverse the system is, the greater its efficiency. The flip side — a degraded life system — is inherently much less efficient and, given its potential to alter the Earth's surface properties, including atmospheric chemistry and climate, in all probability non-sustainable.

## Life as a Part of Earth's System

While this story may seem complex, the central message is this: we are part of a living supra-organism, called Earth. The brilliantly designed architecture and metabolism, tweaked over hundreds of millions of years of evolution has created the exact conditions for life to thrive, despite the huge influx of potentially lethal energy from the sun and the deep freeze state of the universe that surrounds us. The atmosphere, the climate, you and I are the results of the life force itself designing lifeforms and processes beneficial for the whole of the planet, from the humble bacteria all the way to the mighty blue whale and the giant sequoia. But in order to see the wonder that is our planet, we must look much further and recognize the amazing concert of interactions between all species in an ecosystem, all ecosystems interacting together, all moisture streams in the sky and all ocean currents working as one great body for life to thrive and evolve as it has done for billions of years.

## The Urgency of Reversing Climate Damage

The aim of this book is to offer solutions to prevent the collapse of human societies and restore the health of our planet. By repairing the Earth's ecosystems, we can address food and water insecurity, extreme poverty, and inequality. Restoring degraded lands and improving the well-being of communities, especially in the Global South, will not only help stabilize the climate but also reduce the pressures that drive migration and social unrest.

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# Chapter 5
# Climate Chaos Will Curse our Future

Every day of our lives we experience climate. Whether we look out of the window and see cascades of rain falling from the heavens; whether we are out in the blazing Sun; whether we are watching the fury of the seas as massive waves hurl themselves against the shore; or, if we are unfortunate enough to experience the devastating power of hurricanes and typhoons, the bitter cold of a blizzard, the Sun-baked, cracked soil of a crop-killing drought, or floods with water rising up to the eaves, roof and beyond; all these are aspects of climate which in different parts of the world and at different times may manifest themselves. All such phenomena are normal: they are part of life on Earth. Yet, it is with considerable concern that we are now experiencing changes in climate which, right now, are having a devastating impact on our well-being and health. Devastating forest fires, violent downpours, sea surges associated with tropical storms, like the 15-foot surge experienced at Tampa, Florida during Hurricane Milton and long-lasting droughts, like that afflicting the Amazon, are not only more severe than half a century ago, but have become far more frequent.

## The Urgency of Reducing Greenhouse Gases

Climatologist James Hansen warns that if Earth's temperature rises by 2°C by the end of the century, the consequences will be severe. To avoid this, we need to reduce $CO_2$ levels in the atmosphere to 350 parts per million (ppm), but we have already exceeded 420 ppm, a 50% increase since pre-industrial times. If we don’t act, we could see millions of climate refugees each year, as rising sea levels, storms, and crop failures force people to flee their homes.

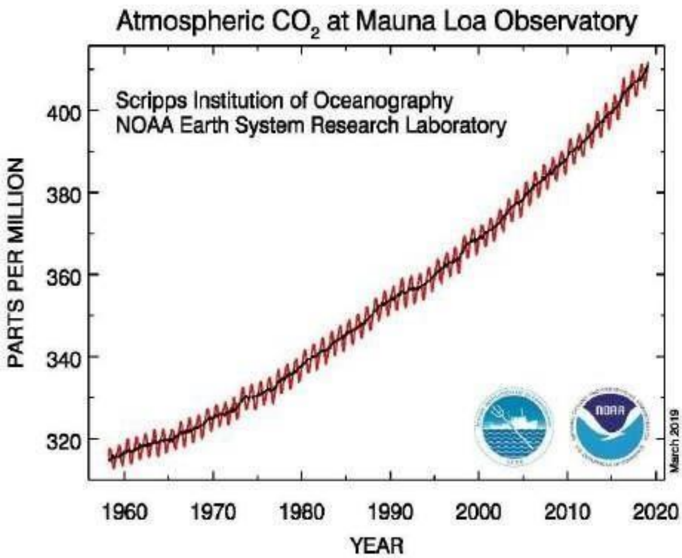



**Figure 26:** *Increasing atmospheric CO2 content over time – Courtesy NOAA*

## Climate Change Consequences

Scientists now predict that extreme weather events caused by future climate change, particularly as they manifest themselves during the latter part of this century, could lead to many millions of refugees, maybe more than 100 million a year, who will be forced to leave their homes and may even have to flee for their very lives. In particular, sea level rise, caused by the expansion of water as it warms and by glaciers melting in the Polar regions, is likely to cause the flooding of low-lying land with saline sea water, especially in the wake of powerful storms.

## The Paris Climate Accord

The Paris Agreement, adopted in 2015, aimed to limit global warming to well below 2°C and pursue efforts to keep it below 1.5°C. It set a framework for countries to reduce emissions and support developing nations in their transition to cleaner energy. While the agreement was an historic step, global $CO_2$ emissions have continued to rise, and in 2023, we saw record-breaking temperatures and accelerating ocean warming. Despite the challenges, the Paris Agreement remains a crucial part of global efforts to combat climate change, but much more needs to be done.

As it is, we are still on a trajectory to suffer the consequences of global warming. By 2050, sea level along contiguous U.S. coastlines could rise as much as 12 inches (30 centimetres) above today's waterline, according to researchers who analysed nearly three decades of satellite observations. In general, it will not just be the fear of drowning which will drive people away from coastlines, but the failure of their crops because of the intrusion of salt water into the soil and fresh drinking water. In Bangladesh, as many as 20 million people are at risk on account of rising sea level. Monitoring over the past 30 years shows that the sea has risen by 5 millimetres a year and could well rise by one metre before the end of the 21st century. Where will all those people go when no longer can they carry on living in the vulnerable delta region, which actually covers a good third of Bangladesh? Will the rest of the world help, especially when the impact of climate change will not be limited to just one region?

Glacier melt is widespread across the globe, in Latin America, North America, Asia and Africa with enormous consequences for drink water and agriculture in these areas. Approximately 2 billion people rely on rivers originating from what has been called the ''Third Pole''. The Hindu Kush-Karakoram-Himalayan Mountain ranges, together with the Tibetan highlands, span over 4.2 million square kilometres across nine countries in High-Mountain Asia, bordering ten nations. This vast region, housing the world's highest peaks, including all 14 above 8,000 metres, earns its nickname owing to its significant ice reserves, second only to the polar regions. This area serves as the water tower for much of Asia. Ten major rivers originate from this area, including the Yangtze, Yellow River, Mekong, Ganges, Indus, Brahmaputra, Salween, Karnali, Sutlej, and Amu Darya. The Third Pole Region, is home to approximately 95,536 glaciers. These glaciers cover an area of about 97,606 square kilometres, according to the Randolph Glacier Inventory

Consortium 2017. The melting and disappearance of these glaciers would be an unimaginable catastrophe.

Glaciers all over the Andes mountains have melted considerably. For example, the Colombian Sierra Nevada Santa Marta lost almost half of its glacier surface compared to 1990 when it had about 10 $km^2$. In 2022, just 5.3 $km^2$ were left. In Colombia alone, according to IDEAM (Institute of Hydrology, Meteorology and Environmental Studies of Colombia) Colombian glaciers have lost 92% of their glacier area since the end of the 19th century.

If anywhere in the world were to be a litmus test that climate change and global warming were a reality, it would be Colombia. *First and foremost*, Colombia is an equatorial country with a foot in both hemispheres; *second*, it has a coastline which stretches from the Pacific Ocean to the Atlantic, with the two oceans separated by the Isthmus of Panama and the Darien Gap; *third*, in Colombia the Andes divides into three distinct chains or cordillera, each with its own range of microclimates and ecosystems; *fourth*, it has the highest mountain massif, the Sierra Nevada de Santa Marta next to the sea of anywhere in the world; *fifth*, it has the highest biodiversity for its size compared to any other country, with more bird species, butterflies and orchids than can be found elsewhere; moreover, because of the Isthmus Colombia has been the gateway over the course of evolution for species to move from Central America to South America and vice versa; *sixth*, and not least, Colombia has a biodiversity-rich part of the Amazon Basin, through which important rivers flow that have been generated in the Colombian highlands.

**Figure 27:** *Lake de La Cocha in Colombia and huge moisture clouds overhead, carried in by the Walker Circulation from the Amazon Basin - Photo Peter Bunyard*

# Chapter 6
# The Amazon: Its Vital Role in Moderating the Climate

Over the Amazon Basin, 2005 was a year without precedence. Never before in recorded history had the region, especially in Brazil, suffered such an extensive and devastating drought, not even in the years of strong El Niños, when the Tropical Pacific Currents switch direction, and the Trade Winds, skimming over the surface from Africa to South America, falter and die away. 2005 should have been a normal, non-El Niño year, with strong Trades picking up enormous volumes of water vapour from a warm tropical ocean, and dumping their load over the humid tropical Amazonian forests of Brazil.

But that is not what happened. Instead, the weather systems of the North Atlantic had transformed dramatically, with the Azores, normally a region of high pressure and sinking air, becoming a region of low pressure, with warm, moist air convecting upwards. Such a turn-around could explain in part why southwest Spain had its first ever tropical storm; why the hurricane track hit further south than normal, striking well within the Gulf of Mexico and washing out New Orleans into the bargain; it could also explain why the Caribbean coast of Colombia was subjected to unprecedented rains in November, causing widespread flooding and deaths; and why the central and western Amazon Basin was left high and dry.

During the Amazonian drought, river levels fell to their lowest ever, and Brazilian authorities declared four municipalities ‘disaster areas’ and another 14 in a ‘state of alert’. Fish died in their millions for lack of oxygen in the turgid waters of the myriads of tributaries that feed into the Amazon River. A heavy layer of cold, dry air had formed close to the ground, encompassing hundreds of thousands of square kilometres, reaching right up into the Colombian Putumayo, and effectively preventing the convection process that leads to thunderstorms and rain. Held down by that layer, the smoke from more than 30,000 forest-clearance fires in Brazil and some thousands of fires in the Bolivian Amazon had nowhere to go, except to make life extremely uncomfortable for people in Brazil, Peru and Colombia, who had to put up with a burning throat and smarting eyes for days on end. Aircraft were unable to land in Leticia and Tabatinga, the latter just across the border from Colombia and, when the smog was at its thickest, no-one dared make the crossing to the other side of the Amazon River for fear of colliding with a floating log, or worse still another boat.

**Figure 28***: Manaus, Amazonas, Brazil, 29 September 2023, View of what's left of the river at Marina do David in Manaus – Photo Jesper Sohof/Shutterstock*

Was global warming to blame? Certainly, sea surface temperatures across the Caribbean were at their highest recorded, not just spawning more hurricanes than ever before, including category 5, Hurricane Katrina, but leaving coral reefs bleached of algae and dying. The loss of the reefs, the loss of mangrove swamps, all led to the coastline becoming ever more vulnerable to sea level rise and storm surges.

But, what about deforestation across the Latin American tropics and in particular across the Amazon Basin? Could deforestation, with resulting alterations in the transport out of the tropics of latent heat in the form of water vapour, have played a role? And what about the biotic pump which draws humid surface air from the tropical Atlantic deep into the Amazon Basin? In that respect, we are being made increasingly aware that even small changes in heat transfer from the equator to the high latitudes, can have a profound effect on weather systems. What should worry us is whether the changes that occurred in 2005 across the tropical Atlantic could become a permanent feature. Were that to be the case, then we could see the demise of the great tropical rainforests that currently cover vast expanses of the Amazon Basin. Under those conditions, South America's agriculture may well not survive in its current form. And where would Brazil get its water to feed its hydroelectric dams that now supply some 80 per cent of the country's electricity?

In 2023, this time during an El Niño year, the Amazon Basin suffered a far worse drought than in 2005, with the same symptoms of large rivers drying out and not just fish dying by their millions, but river dolphins too. Emergencies were declared throughout the southern part of the Amazon in Brazil. Drought, too, affected Uruguay, Chile and Paraguay. The hope was for the situation to improve with the fading of the El Niño phenomenon, but the drying out continued throughout 2024 and, in September, at the border between Leticia in Colombia and Tabatinga in Brazil, the Amazon River was so low that it became practically possible to walk across its wide expanse and cross over into Peru.

**Figure 29:** *August 2024. The Amazon River at Tabatinga, Brazil*

Already, from Tocantins right up to Guyana, we are seeing the Amazon Basin drying out and forming savanna, with its mixture of drought tolerant shrubs and grasses. That may well be the beginnings of desertification, indicating that the natural watering system over South America is breaking down; that the forests are no longer able to sustain themselves. And without the forests, all the countries in South America would suffer dramatic changes to their climate and rainfall. In essence it would be catastrophic. Nor would the rest of the planet escape.

All tropical rainforests affect climate, either locally or regionally, but the Amazon Basin stands out because of its size and therefore its role in using water captured by the Trade Winds of the tropical Atlantic Ocean to provide essential rain to much of the rest of South America. The corollary, that without the tropical rainforests of the Basin, much of South America would suffer a fearful water shortage, is in all likelihood true. The Amazon Basin is also linked to North America, Europe and South Africa by standing waves of humid air that travel outwards from the Basin in a process described as 'teleconnection'. Months after winter rains over the rainforests of the Basin, rain brought in by teleconnection gets to the Corn Belt of the United States, just in time for the Spring spurt in growth. Another teleconnection gets rain to South Africa six months after the winter rains over the Amazon. We are beginning to discover just how important the Amazon rainforests are for the world's climate, once we have worked out the time lags between an event somewhere and its consequences months later.

In effect, Brazil has become a major player in the global soybean market, expanding its land for industrial soybean production, particularly in the Cerrado and Amazon regions. By 2024, Brazil is expected to have 41.4 million hectares dedicated to soy, exceeding the total land area of countries like California and Germany. This growth has pushed small-scale farmers out, as soy production requires far fewer workers compared to subsistence farming. This displacement has fuelled deforestation, on a massive scale, as peasants move to clear new land, especially in the Amazon.

To date climatologists have assumed that the amount of rainfall is dependent on the amount of forest and that as more and more of the forest goes, so rainfall will decline proportionately, akin to a straight line on a graph, until all the forest has one. By using a higher resolution 'mesoscale' modelling – therefore focussing on a limited region, in this instance Rondônia in Brazil's western Amazonia — Roni Avissar, previously at Duke University in North Carolina and now at the University of Florida, and Pedro Silva Dias, from São Paulo, have uncovered a very different picture, with rainfall actually increasing when clearings are not too big, but then after a critical point, dwindling away rapidly and causing the remaining forest in the vicinity to wither and die-back.

Climatologists are now discovering just how important the forests of the Amazon Basin are for regulating climate across the globe. The usual idea of the Amazon Basin is as the lungs of the world, somehow allowing the rest of the world to breathe. But wouldn't savannah or grassland do the job just as well as tropical rainforests and what about the rolling green hills of England? A much better analogy would be that the rainforests of the Amazon Basin are the 'heart' of the world because of all the water vapour and energy that gets pumped out of the region. In fact, tens of times more energy is pumped out than all the energy used by human beings in the world today.

That being the case — that the Amazon Basin is a gigantic irreplaceable pump that gets heat out of the tropics to the higher latitudes and out to Space — perhaps we should start worrying what will happen to climate if we insist on cutting down great swathes of trees. Certainly, what happened in 2005, 2010 and 2023/2024 throughout the Amazon Basin, not just in Brazil, but in Colombia and Peru, should be a stark warning that we may be close to the limits, if we haven't actually gone beyond them.

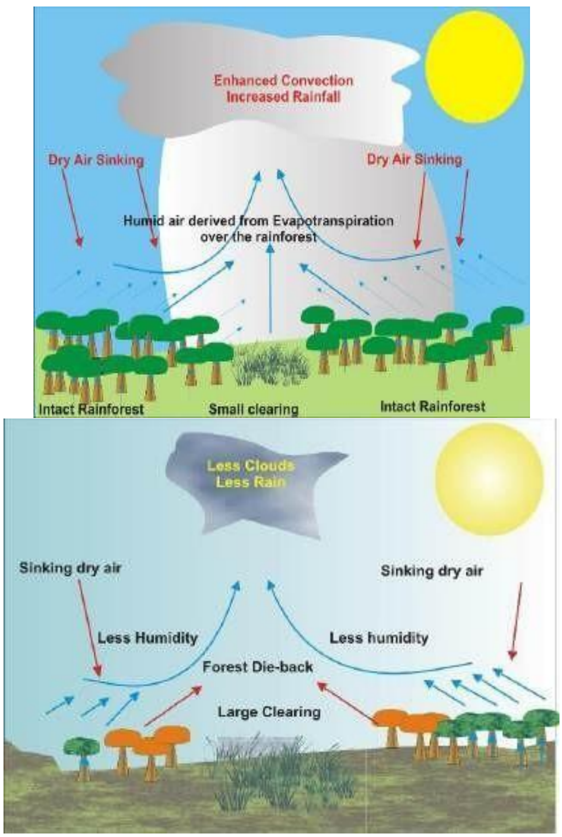



**Figure 30:** *The relationship between precipitation and size of forest clearing. Smaller ones increase precipitation, large one dry out and the forest dies back. – taken from discussions with Roni Avissar by Peter Bunyard*

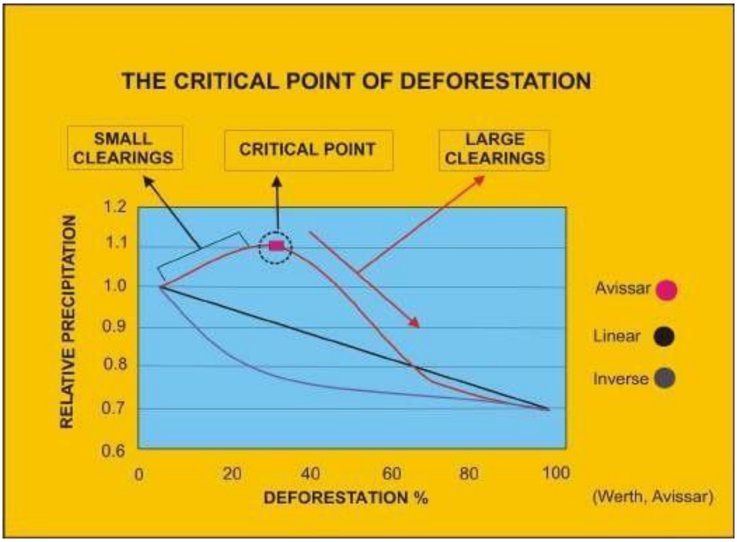



**Figure 31:** *Relation between size of clearing and precipitation – Graph Courtesy Dr Werth and Dr Avissar*

When a clearing is no more than a certain size, probably no more than a few kilometres across, and if the forest around is relatively intact, then the mass of warm air that rises over the clearing, will suck in cooler, more humid, air from the surrounding forest. That convection process leads to the formation of thunderstorms. Under those circumstances rainfall will increase, perhaps by as much as 10 per cent. On the other hand, make the clearing relatively large, when the forest is no longer large enough to moisten the up- draught of air, and the convection process literally runs out of steam. Rainfall then declines sharply.

The Amazon Basin, as it is now, has emerged from a tight association of air mass movements and forest-driven evapotranspiration. In effect, the humid tropical rainforests of the Basin constantly recharge the air flowing above the canopy with water vapour, the net result being that several million square kilometres of forest receive sufficient rainfall for their survival. In addition, just as phytoplankton coccolithophores release cloud forming substances over the fertile parts of the ocean, so too the tropical humid forests of the Amazon release terpenes and isoprenes that, on oxidation, form cloud condensation nuclei. Without such a vapour-cloud regenerating system, those rich forests far to the west of the Basin would in all probability vanish. In effect, the process of downpour and then recharging takes place as much as seven times as the air-mass moves over the Basin, from the Atlantic Ocean.

The forest, as a gigantic, irreplaceable water pump, is therefore an essential part of the Hadley mass air circulation system. And it is that system which takes energy in the form of masses of humid air out and away from the Amazon Basin to the higher latitudes, to the more temperate parts of the planet. Argentina, thousands of miles away from the Amazon Basin gets no less than half of its rain, courtesy of the rainforest, a fact that few, if any of the Argentinian landowners are aware of. And in equal ignorance, the United States receives its share of the bounty, particularly over the Midwest.

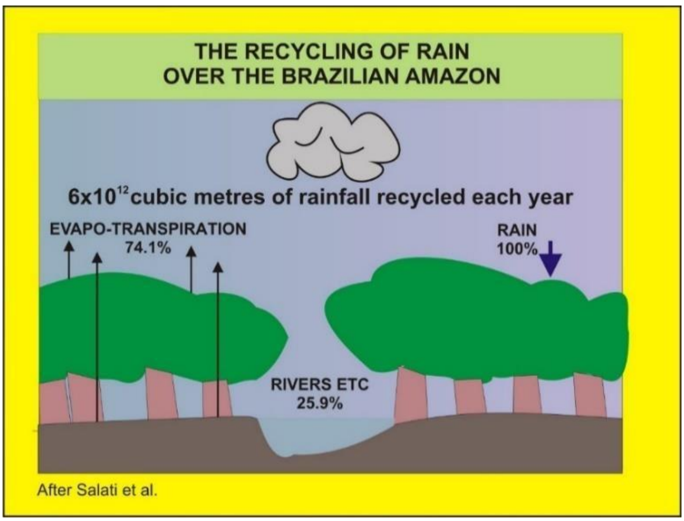



**Figure 32:** *The high rate of evapotranspiration in proportion to the rainfall, combined with the moist air brought into the Amazon Basin from the tropical Atlantic Ocean, leads to more than 50% of the rainfall being recycled some 6 times over the Basin. That recycling by means of the evapotranspiration enables the forest to flourish even thousands of kilometres inland from the oceanic source of the moist air. Graphic Peter Bunyard. (Salati, E., The forest and the hydrological cycle. In: Dickinson, R., Geophysiology of Amazonia, pp. 273-296. New York: W & Sons, 1987.)*

## The Amazon and its Vital Role in Moderating Climate

For 30 years climatologists have questioned what would happen to rainfall over the Amazon Basin were the forest to go, ripped up for cattle pasture, for soya, for timber or as a result of dramatic changes to the air mass circulation brought about through global warming and the continuing, business-as-usual, emissions of greenhouse gases. Would rainfall decline significantly? Could it even go up over the Andes, as the air mass system, embodied in the Hadley Cell Circulation, passed unimpeded across the thousands of kilometres of the Basin?

Most climatological studies of the Amazon Basin, such as those of the UK's Hadley Centre, indicate that deforestation would have little effect along the eastern region of the Basin and at worst would bring about a 15 to 20 per cent reduction in rainfall – one millimetre less than the 5.8 millimetres daily average – in the central and western part. Drastic, yes, but not completely catastrophic.

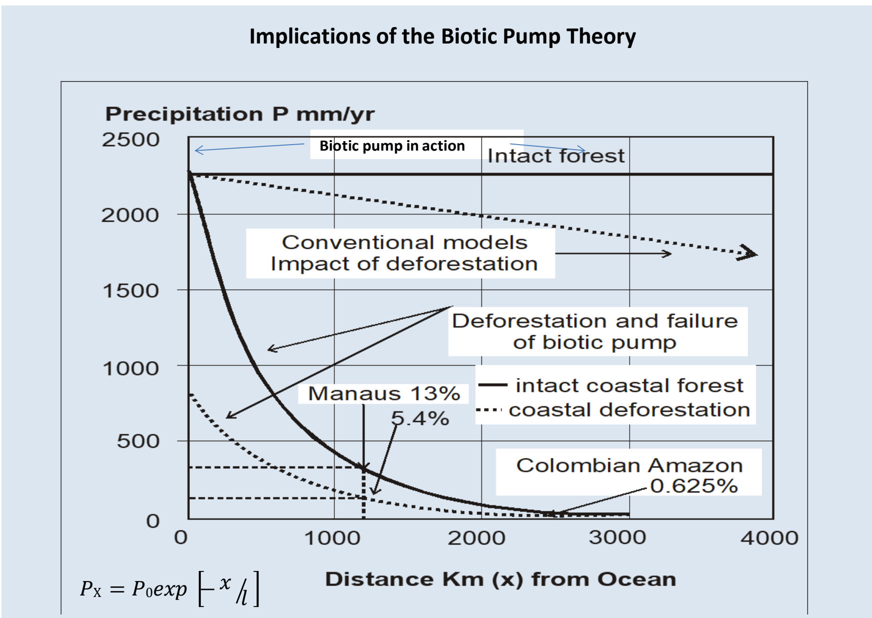
Those conclusions are based on climate models which have been parameterized to agree closely with past data such that when they are 'played' back from present conditions they accord well with general climatic conditions of the mid-19$^{th}$ century. And, for the sake of being more realistic, climatologists, such as Richard Betts at the Hadley Centre, have integrated a terrestrial carbon cycle into their models, with rainfall and temperature critical factors in the maintenance of vegetation cover.

In general, climatologists and meteorologists believe that air currents in the atmosphere are formed through differences in temperature that bring about heat gradients, with colder, denser air sinking and hotter, lighter air rising. Hence, the explanation of the Hadley Cell circulation between Africa and South America. Cold, dense, dry air sinks over the Sahara region of Africa, forming a high-pressure zone. That same mass of air is then drawn over the tropical Atlantic in the form of trade winds from both hemispheres which converge over the Amazon Basin in what is known as the Intertropical Convergent Zone (ITCZ). All of which is helped on its circulation by the Coriolis anti-clockwise spin of the Earth.

However, that view of thermodynamics playing the essential role in the forming of major air currents, such as of the Hadley cell circulation, has now been challenged. Instead, Anastassia Makarieva and Victor Gorshkov at the Theoretical Physics Division of the Petersburg Nuclear Physics Institute, propose on the basis of pure physics that the thermodynamic driver of air mass circulation is secondary to a much more powerful driver which results from a gradient in partial pressure and which is absolutely connected to the evaporation and condensation of water vapour. Based on a physical accounting for changes in partial pressure in the air column and across the horizontal domain of the planetary surface, they conclude that the loss of the Amazon rainforests, for whatever underlying cause, would be disastrous in the extreme, threatening much of South America with unprecedented drought, and leading to desertification in the central and western part of the Amazon Basin, with repercussions right up into the Andes and beyond. If they are right, the very existence of the major river-forming system in the upper moorlands, the páramos, would be threatened, with horrendous consequences for the generation of fresh water resources in countries such as Colombia, Peru and Ecuador, let alone in Brazil.

The logic of the evaporative force, as described in Makarieva and Gorshkov's theoretical analysis of the biotic pump, leads to the conclusion that a continental region devoid of coastal and inland forests which happens to be located next to a warm tropical ocean will display surface air mass movements that are the reverse of those found were that continent to be forested. Thus, whereas the evaporative force over the canopy of a rainforest is considerably greater than that over the tropical ocean, that is no longer the case when the forest is no more. Now, the evaporative force over the ocean is greater than the biotic pump of a depleted vegetation, and the ocean will draw the air mass towards it, thus drying out the continental soils and vegetation in a downward spiral of degradation. Simultaneously, without the rainforest recycling rainfall, precipitation will decline exponentially as one passes from the coast inland.

As Spracklen showed (https://www.nature.com/articles/s41586-022-05690-1), tropical deforestation causes significant reductions in local and regional precipitation, with a particularly strong effect at larger scales. Specifically, for every percentage point of forest lost, he found a measurable decline in precipitation, particularly when looking at regions larger than 50 km in scale. For all that, he takes no account of the biotic pump and a consequent threshold when the pump fails because of excessive deforestation.




**Deforestation impact over the biotic pump. Makarieva & Gorshkov (Makarieva A. M., 2007) use a length of 600 km over which distance a molecule of water will evaporate and fall -out through precipitation.**

**Figure 33:** *When the physics of the biotic pump is taken into account, rainfall declines exponentially over a deforested Amazon Basin. Conventional models indicate a less drastic drying-out. Courtesy Dr. Anastassia Makarieva and Dr. Victor Gorshkov. – Graphic Peter Bunyard*

"Most importantly," according to Anastassia Makarieva, "it was necessary for natural forests with their high leaf area index to appear in the course of biological evolution for evaporation from the forest canopy to exceed evaporation from the open water surface. This allowed life to invade the hitherto dry landmasses by 'sucking' moist oceanic air inland as the forests marched forward from the coast. Not surprisingly, modern global circulation models devised without including the physics of the biotic pump fail radically when attempting to account for the water budget of the strongest biotic pump on Earth – the Amazon River basin."

The implications of Makarieva and Gorshkov's thesis are enormous; essentially it means that South America cannot do without its rainforests, and that instead of quibbling over how much should be conserved, those countries with substantial areas of the Amazon Basin should be doing everything in their power to ensure that no more is destroyed. Furthermore, it means that we should be focussing less on the amount of carbon that forests contain, and on how much forest destruction is contributing to the overall emissions of greenhouse gases, than we should rather be focussing on their fundamental hydrological and therefore climatic role.

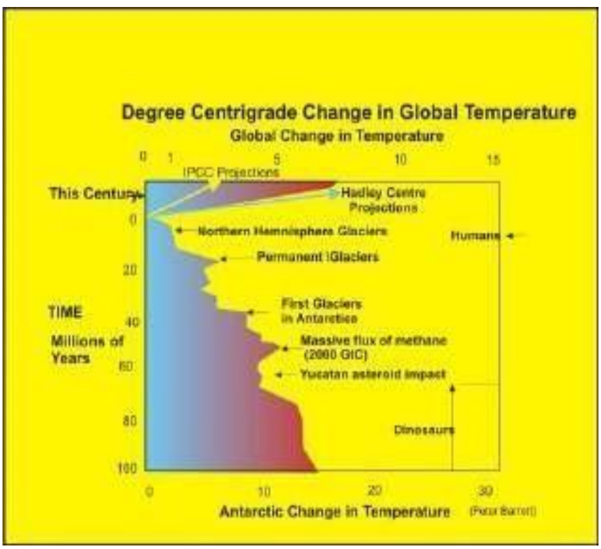
# Chapter 7
# Cooling the Planet with Plants

We know from NASA that the planet is warming, 1.81 watts per square metre was one of their last readings. Taking the entire Earth's surface into account, that means the extra warming since pre-industrial times is equivalent to 0.7 per cent of the solar energy received. At first sight, that does not seem a great increase, at least not until we take account of extreme climate events, be they massive floods, powerful storms, devastating droughts, wildfires, all of which have increased both in frequency and severity. Concurrent with our emissions of greenhouse gases, primarily from the burning of fossil fuels, we have destroyed those very ecosystems which have been primarily responsible for keeping the Earth's temperature at levels that have enabled human beings to elaborate their agricultural systems and thereby to flourish.

In particular, at the urgings of the IPCC, (the Intergovernmental Panel on Climate Change) and the Paris Agreement, the focus is on reducing our emissions of greenhouse gases such as to keep average surface temperatures from rising by 1.5$^0$C, at which point we will be at a threshold, beyond which it will prove nigh impossible to return to cooler temperatures. We have recently passed this threshold for more than 12 consecutive months.

Some 100 million years ago, when the continents were forming their current layout, came the evolution of angiosperm vegetation, with broad, veined leaves. Because of such vascularisation and access to water via their roots, angiosperm trees could transpire at a rate at least four times higher than conifers and more primordial species of trees. With contiguous, closed-canopy forests, that increase in transpiration enabled a higher rate of photosynthesis and consequently a significant increase in biomass, boosted no less by the expansion of forests deep into the hinterland of continents. It is precisely such an evolutionary change which, according to Makarieva, would have served to generate the atmospheric pressure changes we associate with the biotic pump. (see Chapter 6).

That important angiosperm evolutionary step helped bring down the carbon dioxide levels from more than 3,000 parts per million (by volume) to their pre-industrial concentration of 280 parts per million (ppmv). Meanwhile, the biomass converted to coal, which we have been burning indiscriminately once industrialisation got underway. In general terms, over the course of 100 million years, the temperature fell *linearly* from 7$^{0}$C above pre-industrial global-average levels to that at the beginning of the industrial revolution some 250 years ago. Over the same period, carbon dioxide levels fell *exponentially*, with the greatest change occurring all those millions of years back. From the diagram we see that over the past 20 million years the temperature trajectory is more or less linear with bumps, but the $CO_2$ atmospheric concentration shows the tail end of an exponential decline, with relatively little change Yet, the cooling continued over those 20 million years from 2$^{0}$C above pre-industrial levels (280 ppmv) to zero by the turn of the 19th century. (Barrett, Peter, 1999 & Pagani, Mark, 2005).



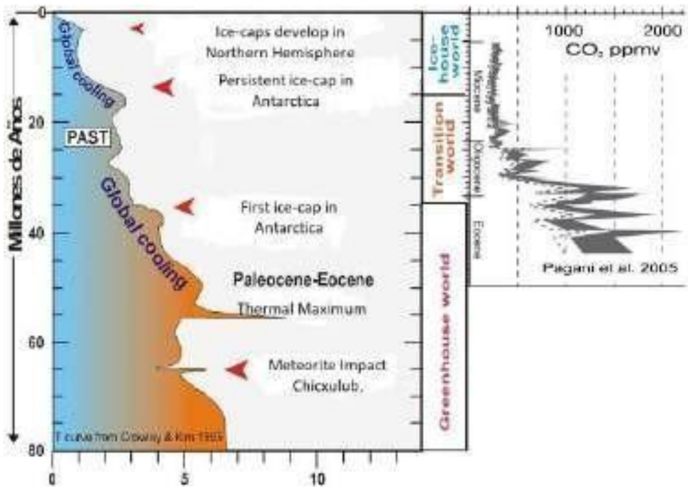



**Figure 34:** *Two graphs showing the correlation but not necessarily the causation between atmospheric* $CO_2$ *and global temperatures – Graphics by Dr. Peter Barrett and Pagani (2005) of the Antarctica Survey.*

The obvious interpretation of the increase in biomass and the associated cooling was that it was the result of $CO_2$ uptake and the reduction in greenhouse gas concentration. Undoubtedly, such a conclusion is in part correct. However, it does not take account of the cooling brought about by a significant increase in evapotranspiration as a result of the evolution of angiosperm-dominated tropical rainforests which, over time, covered much of the continental surface. We calculate that the water-vapour transport of evapotranspired latent heat from the forest canopy to the upper troposphere and its subsequent irradiation to Space as infrared electromagnetic radiation may have brought about a cooling at least 100 times and possibly as much as 200 times greater than the cooling from biomass-forming and its role as a carbon sink.

If, indeed, the angiosperm forests from 100 million years ago to the present day contributed to the cooling of the Earth's surface, most of the cooling because of the transport of energy, in the form of latent heat, from the forest surface to Space, then that process would have given such forests an evolutionary advantage over the non-angiosperm predecessors in two substantial ways: 1) the optimum temperature for growth and biomass production is around $22^0$C and we see today that the mean average temperature at the surface in the forested Amazon Basin is around $25^0$C rather than $30^0$C or more in deforested areas or indeed where the forest has been replaced by plantations such as African Palm; and 2) the high rate of evapotranspiration of the angiosperms triggers the pressure changes which enable the biotic pump to function and bring in additional water vapour from the same latitude ocean, such that the forest can spread to the deep hinterland of the continent. In effect, the forest-generated hydrological cycle, from evapotranspiration to cloud-forming, acts like a vast, natural air-conditioning heat pump.

An important and largely overlooked factor in rainforest hydrology is the biotic pump. The evapotranspiration followed by condensation of water, from liquid to vapour and back to liquid, causes abrupt changes in atmospheric pressure, especially at the altitude where large cloud-masses are forming. In effect, when water vapour condenses, its volume reduces more than 1,200 times. Considerable solar energy is required to transform liquid water to its vapour, just like boiling a kettle. Each gram of liquid water will absorb 580 calories of heat to break the hydrogen bonds that hold the molecules together, such that it can take the form of a dispersed vapour. And, when that same vapour condenses it will release that latent heat energy in the form of infra-red to its surroundings, thereby warming the air in the immediate vicinity of the condensation.

An annual rainfall of 2.25 metres, the average for the forested Amazon Basin, means essentially that 2.25 tonnes of water fall as rain over each square metre of forest. The latent heat in joules for that quantity of rain amounts to 580 kWh throughout the year per square metre of forest. That latent heat on being released as clouds form, will warm one kilogram of air in the vicinity by $2.5^0$C for each gram of condensed vapour.

But that is not the whole story. The sudden, one-thousand-fold reduction in volume, as the vapour condenses, leads to an implosion of the surrounding air to fill the space vacated by the vapour. That implosion is fundamentally the energy of the biotic pump. Using physics we can calculate the energy of the biotic pump being one-fifteenth the energy of latent heat, such that the implosion energy per square metre amounts to 40 kWh. (McIlvean, Robin. 2010).

That implosion energy, hence the biotic pump energy, is not a meagre amount when considering the force that is unleashed in the cloud-forming part of the atmosphere over the Amazon rainforests. In fact, over the entire Amazon Basin of some 7 million square kilometres, it amounts to a force equivalent per second to the distributed energy of an atomic bomb (18 Kilotons of TNT equivalent/bomb). (Bunyard, Peter, simple calculations if we assume 4.18 thousand joules per gram TNT). Given how many seconds there are in a year, the biotic pump energy over the Amazon Basin amounts to more than 30 million atomic bombs' worth of distributed energy.

We can put that gigantic amount of energy into a proportion we can understand by breaking it down into the implosion energy per square metre per second. With an average annual rainfall over the Amazon Basin of 2.25 metres, per day on average, precipitation will deliver 6.165 kilograms of water per square metre. If we assume that such delivery takes place over 4 hours during cloud-formation, then per second the delivery amounts to 0.43 grams of rainfall which generates an implosion energy of 66 joules per second per square metre and a reduction in atmospheric pressure of 0.66 hectopascals per second per cubic metre, as water vapour condenses into clouds. That significant pressure reduction will immediately cause the air from below to flow upwards to fill the partial vacuum at a rate approaching 10 metres per second. 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. Not surprisingly, the air-speed, generated by the biotic pump, is enough to account for the Trade Winds and, therefore, for the watering of the Amazon Basin.

## Threats of Deforestation and Loss of the Biotic Pump

The biotic pump theory underscores the devastating impact that deforestation can have on both local and global climates. Deforestation disrupts the process of evapotranspiration, leading to a reduction in rainfall and the drying out of large areas of land. As forests are cleared for agriculture, cattle ranching, and other human activities, the biotic pump begins to fail, and formerly forested areas turn into savannas or deserts. This process is already evident in parts of the Amazon and other tropical regions, where deforestation has led to severe droughts and changes in local weather patterns. If the Amazon continues to be deforested at current rates, the biotic pump will cease to function, leading to catastrophic climate changes across the globe.

Drought years over the Amazon Basin, such as in 2005, 2010, 2023/2024, are obviously a consequence of diminished rainfall across the entire region and up into the Andean Piemonte. We claim that a reduction in forest evapotranspiration leads to subtle pressure changes in the atmosphere which then feed-back on the biotic pump. We can calculate some of the consequences of that vicious circle in terms of changes to surface temperature, as more heat is held back than would otherwise be the case. Take the year 2005, the average annual rainfall over the Basin was down by 300 millimetres compared to a 'normal' year when rainfall would amount to an average total of 2,250 millimetres. In energy terms, the reduction amounts to 21.5 joules (Watt-seconds) per square metre and, when totalled for the 7 million square kilometres of the entire Basin, it amounts to a value of 16% of the NASA 1.81 watts planetary over-heating. In terms of temperature, the impact of the drought is to bring about a global surface temperature increase of $0.25^{0}$C. That estimate of temperature increase accords with observations, as seen below.

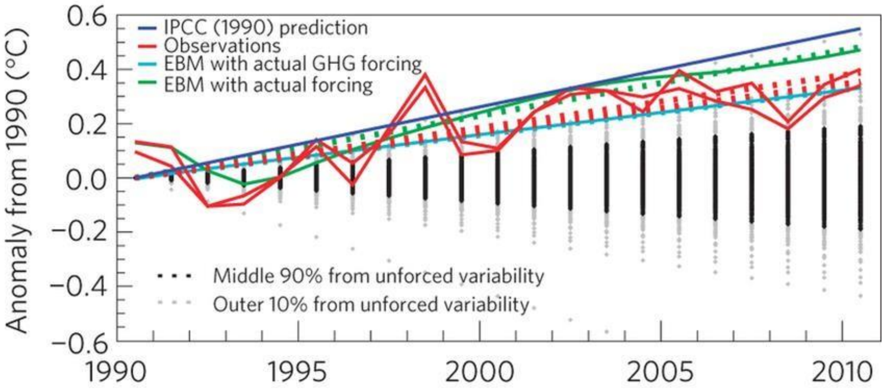



**Figure 35.** *Observations indicate a 0.25PC rise in temperature which coincides with the rainfall decline of 300 millimetres during the drought-year of 2005 over the Amazon Basin.*

## Forest Cooling and Global Climate Mitigation

In this book, we argue that reforestation on a grand scale is one of the most effective strategies for cooling the planet and mitigating climate change.

## Forests cool the planet in several interconnected ways:

1. Transpiration: Forests release water vapour through transpiration, which cools the surrounding air and the forest canopy, with 580 calories per gram of water being absorbed as latent heat.
2. Shading: Closed-canopy forests provide shade, keeping the soil moist and preventing excessive heat buildup.
3. Water Vapour: Water vapour is lighter than nitrogen and oxygen, so that it rises into the atmosphere, carrying latent heat with it. This process helps cool the surface.
4. Cloud Formation: The formation of cumulus clouds reflects sunlight back into space, further cooling the planet.
5. Latent Heat Transport: As water vapour rises and condenses into clouds, it releases latent heat, which escapes into space as infrared radiation – 580 kWh per square metre per year.

6. Lower Bowen Ratio: Reforestation reduces the ratio of sensible heat to latent heat, which decreases the warming effects of greenhouse gases.

Carbon Sequestration: Although less significant than the hydrological processes, forests also act as carbon sinks, absorbing $CO_2$ from the atmosphere.

Consequently, on the basis of the quantity of latent heat, derived from humid rainforest transpiration, which is then released in the upper atmosphere out to Space, we calculate that reforesting an area of 2.8 million square kilometres would reduce global warming by about 0.9°C. This could help mitigate the extreme weather events currently associated with climate change. Additionally, restoring forests would sequester carbon, providing long-term benefits in the fight against rising $CO_2$ levels. *(See appendix for our determination of quantities).*

## Conclusion: The Critical Importance of Forests

The restoration of forests could be a key solution to the climate crisis, offering a natural means of cooling the planet. While reducing GHG emissions is essential, reforestation can provide immediate and tangible benefits by lowering temperatures, restoring rainfall patterns, and absorbing $CO_2$. Protecting the remaining forests, especially in regions like the Amazon, is equally critical to ensure the continued functioning of the biotic pump and the broader planetary climate system.

In summary, forests do more than just absorb $CO_2$; they play an essential role in regulating the Earth's climate by cooling the surface and enabling rainfall far from the coasts. The biotic pump, supported by scientific experiments, shows that forests are vital to sustaining life on Earth by maintaining the hydrological cycle. Without urgent action to stop deforestation and promote reforestation, we risk losing these vital ecosystems, thereby accelerating the pace of global warming.

*For those who like to delve further into the numerical details of the calculations used to indicate the power of cloud-forming in terms of the biotic pump and surface cooling, we suggest you refer to the Annex at the end of the book.*

# Part Two
# Challenges and Solutions:
# A Global Blueprint for Restoration

# Chapter 8
# Regenerate the Great Forests and Grasslands

''Forests precede civilizations and deserts follow them'', Francois-Rene de Chateaubriand

**Contributing Author Dr. Rodger Savory**

The web of life on our planet has transformed it into a superorganism, with ecosystems regulating, on a moment-by-moment basis, the composition of the atmosphere and even the saltiness of the sea. On our planet everything is interconnected, from the flow of minerals in a cowpat, washed by rains into streams, rivers and then the sea, to seals which had fed from fish that had incorporated the cowpat minerals and on to polar bears hunting those seals from platforms of ice in the Arctic Ocean. Such interconnections create complex feedback loops incorporating the ebb and flow of minerals and nutrients which are essential for life as a whole. In effect, an absolute plethora of life-driven feedback loops, some positive and causing an accelerated move to another state, others negative and dampening down such trends, work together to ensure the flow of minerals and nutrients that provide the bedrock of essential metabolic processes. Just as we expect the Sun to shine, we take it for granted that fresh air will have just the right oxygen content for us to breathe, all the while forgetting that it is the bounty of life, by means of photosynthesis, which has generated the oxygen of the atmosphere in the first place.

As we have described in detail, forest ecosystems, by means of evapotranspiration, create clouds that bring rain, and in so doing, generate the very winds, by means of the biotic pump, which carry the humidity-laden air from the ocean to the continental interior. That way, the great forests, such as those of the Amazon Basin, help generate the great cyclic movement of the tropical air mass, the Hadley Cell Mass, which passes over the ocean and between continents, for instance between Africa and South America, with the surface stream carried by the Trade Winds and the upper air, dry and cold, carried back to Africa in the Jet Stream, where it sinks to start the cycle anew. Through those processes the rainforests cool the planet through increased cloud-albedo and through transporting latent heat energy to the outer atmosphere where it dissipates into space as electromagnetic radiation.

**Figure 36:** *Serengeti Landscape in Tanzania, Africa – Photo by Javier Hueso/Shutterstock*

Restoration of tropical forests on a sufficiently large scale could stop the planet from heating up further and we calculate the amount of land needed to be covered again with tropical rainforests and agroforestry would be in the region of an area the size of India, hence 3 million square kilometres. This can technically be done if the world empowers, pays and activates the 500 million rural smallholder families in the Global South to make the transition to agroforestry and forest conservation in their regions of Latin America, Africa, the Indian subcontinent, South-East Asia and the tropical islands in the Pacific. Rob de Laet, one of the authors, has proposed a business plan for that, called *Arara,* which is the indigenous name for the famous scarlet macaw. The initial investment would be in the realm of 3,000 to 5,000

USD per hectare, with a total price tag of 900 billion to 1.5 trillion USD spread out over a period of ten years. The effects on climate, poverty alleviation, food and water security, biodiversity protection and migration to the Global North would be phenomenal.

## Grasslands and Savannas Regulate the Nutrient Cycles

Over half of the world's land surface consists of vast tracts of land covered by grass, shrubs or sparse, hardy vegetation. The largest are the Eurasian steppe, stretching all the way from Hungary to China, the North American Great Plains, the grasslands of South-America such as the Pampas, Cerrado, Llanos and Gran Chaco. In Africa we have the huge grass plains like the Serengeti, large parts of the Sahel and in Southern Africa the savannas of Zimbabwe, Zambia, South-Angola and the South African bushveld. Large parts of Australia are covered by savanna. These areas support millions of pastoralists, hunter-gatherers, ranchers and the largest populations of wildlife that still roam the Earth. These grasslands store large amounts of carbon and regulate their climates with little water. In addition, crops such as wheat, maize, soy beans and cotton are produced on these plains. Yet, while most climate plans focus on forests, much less importance is given to rangelands, leaving these massive planetary ecosystems exposed to a wide variety of threats.

With their deep-root systems that help secure the soils against erosion, intact grasslands are biodiverse rich. Furthermore, over time, they accumulate substantial quantities of carbon- rich substances in their soils, increasing their fertility. The carbon in a tropical forest or jungle is cycled daily via insects, fungi and microorganisms. The same recycling goes for grasslands, but with the difference that great herds of herbivores, like the buffalo of the Mid-West or wildebeest of South Africa, contribute significantly to nutrient-cycling, helped on by a similar trio of organisms, insects, fungi and microorganisms, that we find in the rainforest.

All the world's great prairies, plains, veld, and savannah have a wet season and then a dormant or dry season. The dormant period can be from a few weeks, to months, or even years. For that reason, such regions are deemed to be brittle and therefore vulnerable environments. Nevertheless, that ‘brittleness’ is countered on account of the rich biodiversity of healthy grassland ecosystems. Indeed, such ecosystems have been found to have over a hundred species of grass, over a thousand legume species, several thousand herb plants and over ten thousand fungi species. Whereas trees in the forest drop their leaves to the ground, where they decompose, grasses do not shed their leaves and instead rely on grazing animals to establish the recycling of nutrients. The impressive migration of herds of ungulates, such as antelopes, zebras and bison, therefore play a crucial role in maintaining the world’s grasslands through accelerating the recycling of nutrients from their dung, their urine and their belching, which releases methane. The methane oxidises to water and $CO_2$, thereby putting carbon back in the atmosphere for photosynthesis, as part of the natural cycle between vegetation and the herbivores.

The dung beetle provides a fascinating addendum to the story of recycling and the way they go about their ‘business’ is a classic in ecosystem management. Some species of beetle, as in the African savanna, make a tunnel running deep down from the surface. Then, having taken a piece of dung and rolled it into a ball, often far bigger and heavier than itself, it pushes the ball down the tunnel, to feed itself and offspring. By aerating the soil, by distributing both the nutrients and the grassland or forest seeds contained in the dung, by allowing rain to penetrate the soil, they have been found to significantly improve the ecosystems of which they are part. Lands which have been sprayed with insecticides and which have therefore lost their dung beetles become increasingly infertile.

Healthy grasslands prevent desertification. Most deserts have been caused by human land- use change, including the South Western United States Great Desert, the Sahara Desert, the Arabian Desert and

Gobi Desert, all of which used to support great herds of ungulates before humans killed them off. We have evidence of vast herds, including elephants and giant bovines in all current deserts. Once, Man had killed off the herds, then the water cycles stopped functioning, the rivers dried-up, and the grasslands died. The Atacama Desert and the coastal Namibian Desert are exceptions to the rule that deserts are primarily man- made inasmuch as both are coastal deserts which are formed by cold offshore currents.

With the introduction of holistic grazing management, we are now able, quickly, cheaply and effectively, to convert former deserts back into healthy functioning food producing, habitat enhancing, climate cooling and stabilising grassland ecosystems that can support vast herds of grazing animals and the families which rely on them. At the same time, we need urgently to get this knowledge into mainstream thinking, so that the lands, which are currently supporting people but, through malpractice, are undergoing a process of desertification, can be regenerated. For the first time in human history, we now know how to halt and reverse desertification on a macro-scale.

## Temperate and Boreal Forests Irrigate the Landmasses of the Northern Hemisphere

The temperate and boreal forests are mainly found on the landmasses of the Northern Hemisphere. Temperate forests are characterised by broadleaf deciduous trees, such as oak, maple, and beech, as well as conifers, such as pine and spruce. Boreal forests, in contrast, are dominated by evergreen conifers, such as spruce, fir, and pine. Beginning slightly beneath the Arctic Circle, the boreal forests stretch across most of the Northern Hemisphere, forming a verdant halo around the globe. They represent one of the planet's final vast wild spaces. These vast woodlands, home to many Indigenous peoples, teeming with ancient conifers and birches and are populated by a diverse range of creatures from wolves and caribou to loons and wood frogs. Crucially, these forests also hold between 30 to 40 percent of the world's terrestrial carbon, positioning the boreal as a frontline in combating climate change.

During the growing season, the boreal forest generates the hydrological conditions for a functioning biotic pump. The pump is a major driver for atmospheric moisture transport from the Atlantic Ocean, over several thousand kilometres, all the way to the other side of the Eurasian continent while, on the Alaskan/Canadian side it drives moisture from the Pacific all the way to the Atlantic. Recent deforestation and tree dieback in European Russia and Canada are disrupting this pump mechanism, therefore bringing about diminished precipitation and over the Arctic Circle a reduction in ice-forming such that the exposed sea absorbs more heat, more ice-melting during the summer months, in a vicious positive feedback circle. According to Indigenous voices, the boreal forests are responsible for keeping the polar areas frozen.

## The Smallholder Farmers of the World can Save the Climate!

The only group that has the expertise and numbers to save global human society from climate breakdown are the people we have neglected most, the around half a billion smallholder farmers around the world, 97 percent of whom live in the Global South. These farmer families with areas less than two hectares per family are the only group of people who understand the land, know how to work the land, and make a living off the land. They produce a significant portion of the world's food, especially in developing countries. This large group of people, which may be as large as three billion individuals, play a vital role in food security, biodiversity, and sustainable agriculture.

From calculations, we know that we could significantly reduce global warming by reforesting and instituting agroforestry systems over an area of around 280 million hectares in the tropics. In fact, the ''stand alone'' effect of such an effort would reduce global temperatures by nearly 1 degree centigrade. If achieved, such regeneration would have tremendous positive effects on local micro-climates, precipitation, water cycle management and food security whilst potentially doubling the income of smallholder farmers. The impact would even be greater once we use regional climate resilient landscape design to include the patterns of reforestation to activate the biotic pump function of forests, starting at coastal areas. In fact, we can significantly improve the weather through large scale restoration of forest landscapes.

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Chapter 9

# Rehydrate the Lands by Restoring Water Cycles

*This chapter was prepared by Zuzka Mulkerin* zamulkerin@me.com

The water cycle describes where water is on Earth and how it moves. Water and geological processes have shaped the Earth's surface for billions of years. Water and the water cycle together with living organisms have been instrumental in developing the Earth's atmosphere. Free oxygen in the atmosphere is the result of the activity of autotrophic, photosynthetic organisms (stromatolites) that evolved along shorelines some 3.5 billion years ago. This was the beginning of aerobic metabolism and enabled the evolution of higher organisms, including higher plants. We have seen in Chapter 7 how evolutionary changes concerning flowering plants brought about dramatic changes in evapotranspiration and its impact on the water cycle.

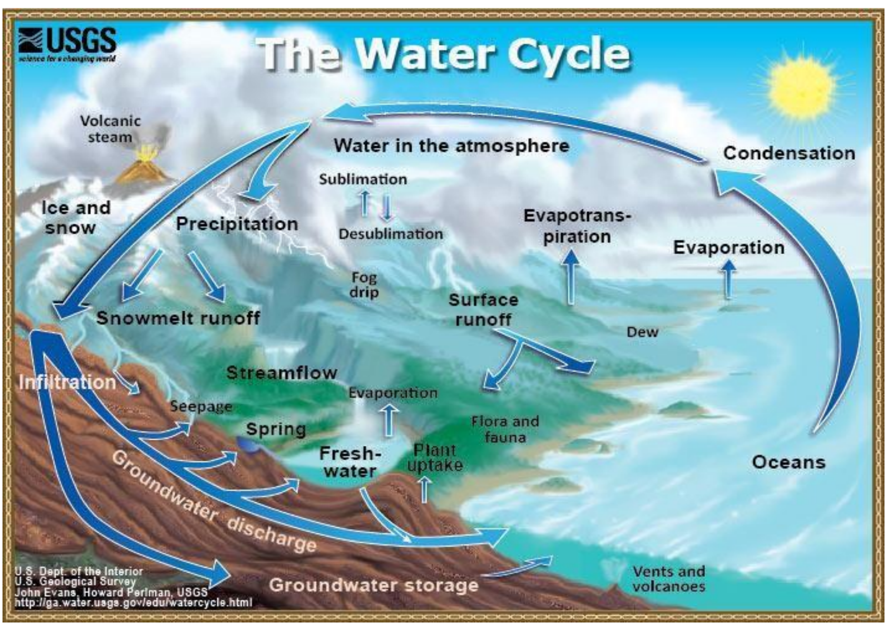


**Figure 37:** *The Water Cycle – Courtesy US Geological Service*

The biotic pump phenomenon explains how we can restore the small water cycle as a result of condensation-caused pressure changes which draw in humid surface air from the same latitude ocean. Meanwhile, evapotranspiration of rainwater, particularly through angiosperm trees, intensifies the large water cycle, which determines how much moisture is imported from the ocean. This influx, which in the steady state is equal to the river streamflow, determines among other things how full the rivers are. The mightiest rivers on Earth are where the vegetation is flourishing.

Evapotranspiration feedback in the region– a small water cycle - is what our ancestors have known for millennia. Small water cycles (or "short water cycles") present the vital interactions of water vapour, plants, and solar energy in creating and maintaining a liveable climate. The small water cycle can be described as the closed circulation of water in which water evaporated on land (or water) falls in the form of precipitation over the local region.


**Figure 38:** *Some of the oldest life forms on Earth, Stromatolites – Peter Bunyard, Climate Chaos (2010)*

That forests regulate water stormwater run-off, mitigating risks of flooding and drought, has been recognized since ancient times. The ancients also understood that trees can increase rainfall and deforestation can reduce it. Cutting down trees leads to a reduction in evapotranspiration, which results in less downwind precipitation. In that respect, widespread deforestation is creating a catastrophic situation that threatens to disrupt Earth's climate and cause havoc with rainfall patterns.

Despite all that we now know concerning the role of forests in maintaining a healthy water cycle, forests are still being chopped down. According to the main compiler of forest data, the UN's Food and Agriculture Organization, about 4 billion hectares (10 billion acres) of forest remain, covering 31% of the Earth's land surface. Only a third is primary. Much of the rest is seriously degraded: the FAO's definition of a forest takes in areas with as little as 10% tree cover. Preserving the existing pristine forests, and actively restoring our watersheds is the way to heal our climate.

The absence of small water cycles intensifies storms. Wetlands reduction, corrupt agricultural practices, and negligent stormwater management all go together to reduce watershed function and cause landscapes to dry up. Current human-made landscapes are often based on the notion that rainwater is an inconvenient waste and disposal problem, to be sorted by accelerating drainage and runoff anytime the rain falls on the ground. Indeed, for centuries, humankind has greatly interfered with local water cycles by way of poor agricultural methods and deforestation that lay bare the soil. Municipalities drain stormwater away to keep the urban areas dry. Yet, eventually, cities will suffer unprecedented heat waves owing to diminished moisture in the ecosystems, with loss of both evaporation and groundwater recharge. In fact, urban and real estate development is annually responsible for 57,000 $km^2$ global runoffs. In the pursuit of food supplies and arable land, people cut annually about 127,000 $km^2$ of forests. Corrupt agricultural practices cause an annual drying up of over 200,000 $km^2$ of farming land.

Consistent and widespread restoration of native vegetation and soil fertility will bring about restoration of the natural water cycle. Integrated watershed restoration will also achieve increases in food production, fresh water supplies, and biodiversity, while mitigating the occurrence of severe weather, and decreasing the volumes of storm water flowing down rivers, thus ultimately decreasing sea levels.

To quench our lands' thirst, we must adopt two key strategies: retaining rainwater and restoring natural vegetation. Governments, businesses, and communities can play a role in promoting water retention efforts and reforesting degraded landscapes. Projects focused on protecting old-growth forests and revitalizing watersheds through afforestation can recharge small water cycles and contribute to climate stability.

The world is full of success stories of landscapes and waterscapes brought back to life through simple water-retaining practices. Whether in a tiny village in India or a large metropolis in America, the concept is the same: save the rain in the land on which it falls, and the rewards will be great. Saving water takes many forms, depending on whether the setting is on a farm or ranch, in a tiny village or a huge city, in a forest, or at the roadside. We can relatively quickly cool our local and regional climates by working with nature as plants and watersheds cool the Earth. Human communities can work on restoring abundant plant life and a functional soil sponge to slow, sink, and soak up the rain. A soil carbon sponge is created by plant roots, microbes, and other soil life.

Forests and wetlands are ecological miracles as managers of water, makers of rain, consumers of carbon, and biodiversity habitats. They must not be allowed to vanish. Douglas Sheil, the coauthor of a research study on atmospheric moisture notes that implications are profound: “We have yet more evidence that we disrupt the natural world at our peril,” he says. “But there is also a positive message: we need nature, and we can defend it and achieve many other benefits at the same time. This study is about the reliable rain that we all depend on. But the solution is to maintain and regain forests and wetlands, that also protect biodiversity, store carbon, and provide many other vital goods and services."

**Figure 39:** *Evapotranspiration creating early morning fog in dense tropical rainforest – Photo by Stephane Bidouze/Shutterstock*

Plants, particularly trees, perform an amazing cooling and moderating role in the small water cycles. Thus, temperature differences are moderated in time and space. New, expanded water management policies will enable the United Nations to carry out its strategic decision to focus on green growth, efficient use of natural resources, and resilience to natural disasters; economic security will be increased not only in the water sector, but also related sectors that encourage and foster innovation for sustainable communities and economic prosperity of nations. By means of restoration of ecosystems and water retention strategies, UN member countries can ensure their water security by using the best available techniques and measures. They can reduce the vulnerability of their own countries to floods, droughts, and natural disasters, while simultaneously improving soil fertility, biodiversity, groundwater supplies, and the moderating effect of small water cycles on regional climates. Joining with other nations in a united effort will help bring about environmental healing on a global scale.

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# Chapter 10
# Restoring the Oceans

*Written by a team of experts from the EcoRestoration Alliance*

Not so long ago, the oceans teemed with life. As explorer Captain John Cabot sailed from England to North America in 1497, his ship encountered massive schools of codfish off the coast of Newfoundland. The fish were so abundant they brought Cabot's vessel to a halt, even under full sail. Cod the size of ten-year-old children filled the sea from the surface to the seafloor.

The oceans of that era contained gigatons more fish biomass than they do today. Phytoplankton blooms turned vast swathes emerald green and, from the coccolithophores, chalky white. Coral reefs and oyster beds flourished along every coastline. Whales, walruses, sea turtles, and seabirds crowded the waves. It was a marine world bursting with abundance and diversity.

Now, after a few centuries of exploitation, the oceans are a shadow of their former glory. Overfishing has decimated fish stocks and removed vital links in the food chain. Runoff pollution from agriculture and industry has created vast dead zones devoid of oxygen.

Acidification from excessive $CO_2$ and pollution have damaged coral reefs and shellfish and fish--an estimated 90 percent of large fish populations have disappeared, along with over half of phytoplankton species.

This loss of ocean life has dire consequences for climate stability. The living biomass that flourished just 300 years ago could have sequestered all the excess carbon released by burning fossil fuels. The evaporation and cloud generation from trillions of swimming, respiring organisms that helped regulate temperatures worldwide has now been hugely depleted. And the reefs and food webs that fortified habitats and protect coastal communities from storms and erosion are in critical condition.

## All Ecosystems Interact and Reinforce Each Other

While this chapter is about the oceans, we must also focus on the connective tissue of ecosystems that form the transition between land and oceans. The land-water interface everywhere is a very productive and biodiverse part of the biosphere, at least when not degraded or destroyed as is often the case as humans have a preference for living on this part of the land. The nutrient cycle interaction between oceans and land is a crucial part of a well-functioning biosphere.

## The Story of the Salmon and the Forests

A beautiful example of this interaction is that between salmon and forests. These amazing fish get born high upstream in rivers and streams. Leaving their freshwater birthplace, they embark on a daunting voyage to the saltwater depths of the ocean. Years pass as they grow and thrive in the vast expanse of the sea. However, the call of their natal river, imprinted in their very essence, guides them back home. The salmon's return journey is no less challenging. Against strong currents and over cascading waterfalls, they swim upstream as their instincts urge them to complete their life cycle, to lay eggs, fertilise them and ensure the next generation. Here they die and their bodies decompose. Their bodies then release a wealth of marine-derived nutrients, rich in nitrogen and phosphorus, into the ecosystem.

These nutrients nourish the soil along the riverbanks. Nearby trees and plants absorb these nutrients which invigorates the health of the surrounding forests, which in turn shelter and feed insects and birdlife. The impact of the dead salmon reverberates through the ecosystem. Biodiversity flourishes as the forest becomes a haven for life, thanks to the nutrients released by the salmon. But the story does not end there. The nutrients that feed the forest also create strong root systems that stabilise riverbanks, which prevents erosion and ensures clear water.

## The Interaction between Sea Ice and Ocean Life

Another very productive edge is the place where sea ice meets open waters around the poles. The life of phytoplankton, zooplankton and especially krill is especially prolific in these areas which not only sequesters $CO_2$ but also helps to mix ocean layers and nutrients together with waves, winds and currents. When these edges between land and sea and ice and sea are healthy, life thrives enormously.

## Back to the Oceans

The oceans comprise over 70 per cent of the planet's surface and have immense potential for rapid restoration. Within just a few decades, strategic interventions could revive marine productivity, biodiversity, and climate regulation on a massive scale. We know ocean phytoplankton and zooplankton can bloom exponentially, as they have rebounded rapidly from previous mass extinctions and bloomed in response to environmental events. Selective iron fertilisation for example, if done responsibly, can stimulate algal growth that pulls carbon from the air far more efficiently than planting trees. Restoring whale populations will also enhance vertical mixing and carbon sequestration. And marine protected areas can allow fish stocks and food webs to recover with spillover effects that replenish commercial fisheries.

Coastal habitats, like mangroves, sea grasses, coral reefs, and oyster beds, similarly sequester carbon, nurture ocean ecosystems, protect coastlines and feed humans. They, too, can be regenerated quickly and profitably through human restoration efforts.

Technologies have emerged that address the key problems found in dead zones, namely low pH, low dissolved oxygen and harmful algae blooms (HAB). Even a small revival of ocean life and coastal systems will seed more clouds that reflect sunlight and facilitate heat loss to space. Recent measurements have shown that the Earth has become darker by about 2 per cent, thereby absorbing more of the sun’s light. Loss of low-level clouds and sea ice are two of the main causes. Sir

David King, erstwhile chief scientist of the British government estimates that carbon sequestration capacity of the oceans in tens of gigatonnes of $CO_2$ per year.

We have ample reason to believe that within a few decades, ocean restoration could compensate for all fossil fuel emissions to date. As we will see, in combination with land restoration and emissions reductions, the attendant cooling and carbon processing effects would potentially keep $CO_2$ levels and temperatures from going beyond the $1.5^0C$ `disaster threshold` and eventually even bring them back to pre-industrial levels. While the threshold will likely be breached already this decade temporarily, action at speed and scale may counter that if humanity wakes up to the profound benefits of ecosystem regeneration and acts upon them! By combining emerging science with traditional wisdom, choosing interventions with care, and investing in ocean restoration worldwide, we can recreate balanced marine ecosystems that sustain climate equilibrium, food security, and human livelihoods far into the future. Our healthy oceans can thrive again and in the process be a timely and major factor in the cooling of our planet. Some of these effects (e.g. the right kind of algal blooms) can kick in within months of treatment. There's no time to waste.

## Scientific Background

From a planetary perspective, the oceans and the atmosphere are thin films of liquid and gas enveloping a molten sphere of rock covered by a thin crust. The sun pours energy on to the planet, especially at the equator, while the earth's daily rotation causes winds to blow from East to West near the equator, creating ocean currents that move energy, heat, and nutrients horizontally and vertically around the planet. When those westerly ocean currents collide with land masses, up- and down-welling occurs. Upwellings bring to the surface minerals and nutrients that living things use to convert solar energy into biomass, much of which eventually sinks to the ocean floor. Down-welling brings oxygen to life-forms that dwell in the cold dark depths.

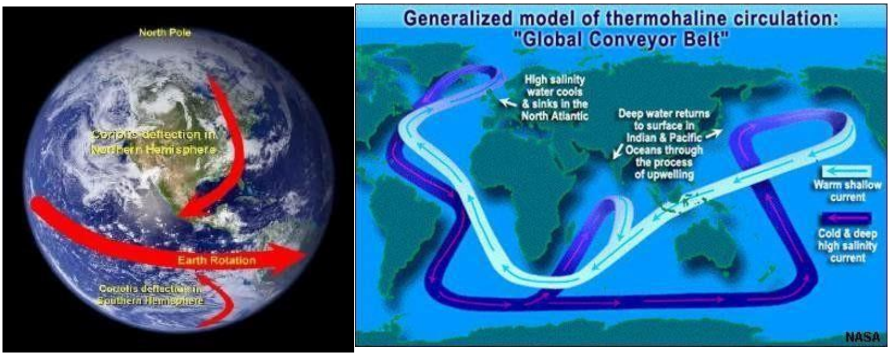


**Figure 40:** *Overview of Coriolis effect on Wind patterns and Thermohaline Circulation – Courtesy NASA*

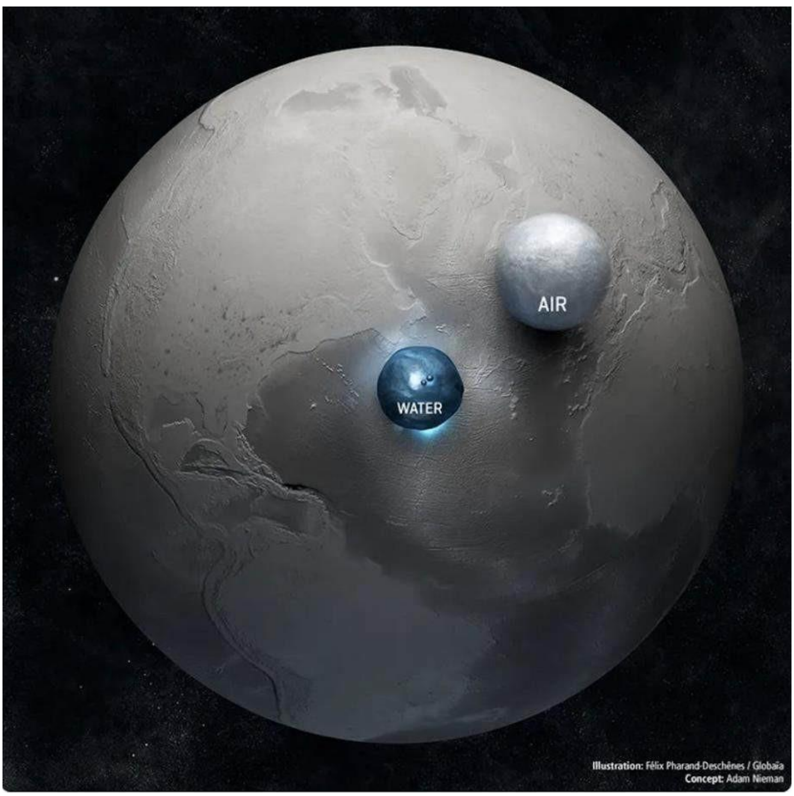


**Figure 41:** *Life on earth depends on a small quantity of water and air. All of the air and much of the terrestrial freshwater wouldn't exist without healthy ecosystems. The blue marble shows all available water, the tiny dot on top of the water marble is the pittance of fresh water we have on our planet – Copyright Adam Nieman*

Life evolved in the oceans and coasts washed by tides. It colonised the land 500 million years ago. Life, in general, created the liveable climate and breathable atmosphere we take for granted, and their evolved interactions with sunlight, carbon and water have moderated and stabilised global climatic patterns upon which they and we depend. When photosynthetic plankton use solar energy to convert atmospheric carbon into living organic carbon compounds and aerosols, they cool the planet not just by lowering greenhouse gases, but by stimulating clouds that reflect sun out to space, bring snow to the glaciers, and fresh water to the continents. Over the aeons, these polar and continental influences have modulated global weather patterns to create conditions that have become increasingly conducive to life as we know it. All that and more is now threatened by the unprecedented emergence, unchecked proliferation and outsized impacts of one terrestrial species.

*Homo Sapiens* emerged a few hundred thousand years ago. For most of that time our impact on the Earth's ecosystems was limited though, with the killing of megafauna and the cutting of trees, we probably started to change the balance already tens of thousands of years ago. But in the last 500 years colonialism and industrialism have created a destructive dynamic: we have become massive destroyers rather than beneficiaries of the earth's abundance. In the last 80 years, pesticides, pollution, and plastics (the 3 Ps) have destroyed plankton at the bottom of the food chain, simultaneously as increasingly efficient industrial fishing practices depleted the top of the food chain. Marine mammals, such as those which feed on plankton, send huge amounts of carbon to the ocean depths and circulate nutrients that support ocean life. They have been hunted to near extinction. Ocean life has been severely reduced over the last decades owing to overexploitation, pollution and the impacts of climate change. The deterioration is accelerating and the climate-stabilising influences of living ocean biology are waning fast, already impacting weather and climate.

We need to fix this disastrous situation right now. To restore the oceans, we need to understand the interactions of ocean life with the atmosphere, with the cycles of carbon, phosphorus, nitrogen, and iron, as well as with natural and man-made substances that enter the seas from land.

Our emissions from fossil fuel burning exacerbate the $CO_2$ greenhouse effect, essentially by preventing the radiation out to space of the Earth's sun-warmed surface heat. But to focus on $CO_2$ is to miss the big picture. The dominant greenhouse gas is not carbon; it is water vapour (96 per cent of greenhouse gases). Since seventy percent of the earth's surface is water, the state of the oceans is a critical determinant of water vapour, clouds, and the air we breathe. These in turn are all determined by carbon-based life forms that consume, embody and assimilate $CO_2$. The single-celled coccolithophores, for instance, make their shells out of calcium carbonate, and when they die, a proportion of their shells sinks to the bottom of the ocean and over millions of years accumulates to form cliffs such as the White Cliffs of Dover and even mountains such as the Dolomites. With the loss of such phytoplankton, less carbonate is taken out of oceans, thereby leading to more carbonic acid and general acidification. A warmer ocean also holds less $CO_2$ and the outgassing leads to yet more $CO_2$ in the atmosphere.

## Open Ocean

The image below shows how the ocean currents are influenced by latitude and proximity to land. At the poles, oceanic water vapour which converts to snow produces glaciers, and once the temperature falls well below freezing forms sea ice and, because salt is left behind when water freezes, a layer of cold water which is dense with salt. The cold dense salty water sinks and, driven by the oceanic conveyor belts, flows at depth from the Poles to the equatorial oceans.

The sinking results in less-salty warm water from the Tropics, flowing from low to high latitudes on the surface to replace that which has sunk. That circulation gives us the Gulf Stream which carries sufficient heat to keep the western side of Europe and even Scandinavia significantly warmer than it would be, were the Gulf Stream to fail.

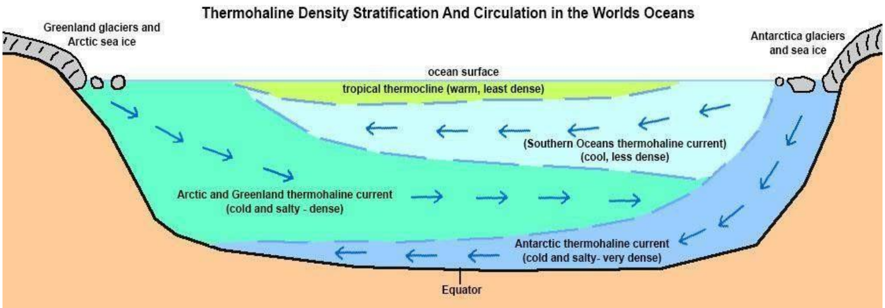


**Figure 42:** *Representation of ocean circulation partly driven by salinity stratification – courtesy Phil Stoffer at Miracosta Education.*

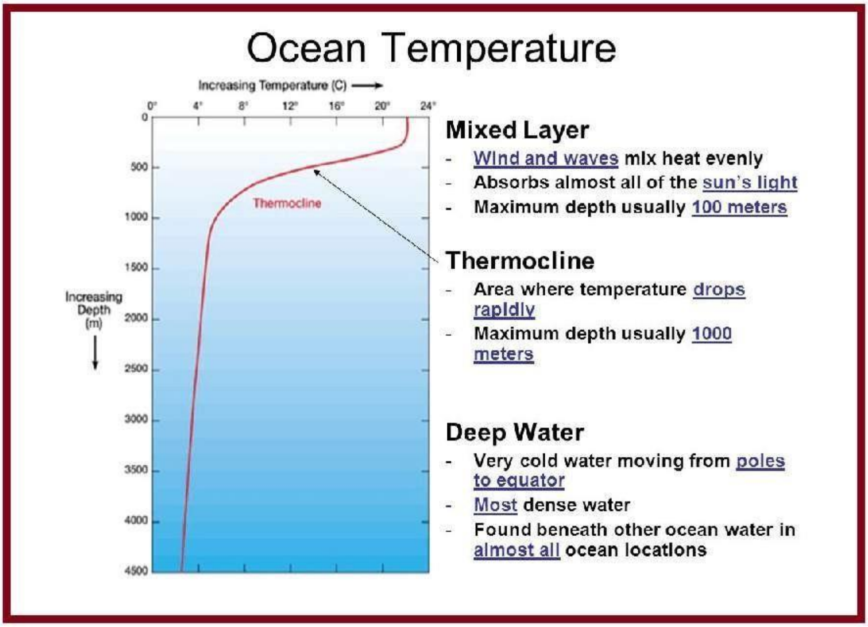


**Figure 43:** *Ocean Temperatures and the thermocline – courtesy Phil Stoffer at Miracosta Education.*

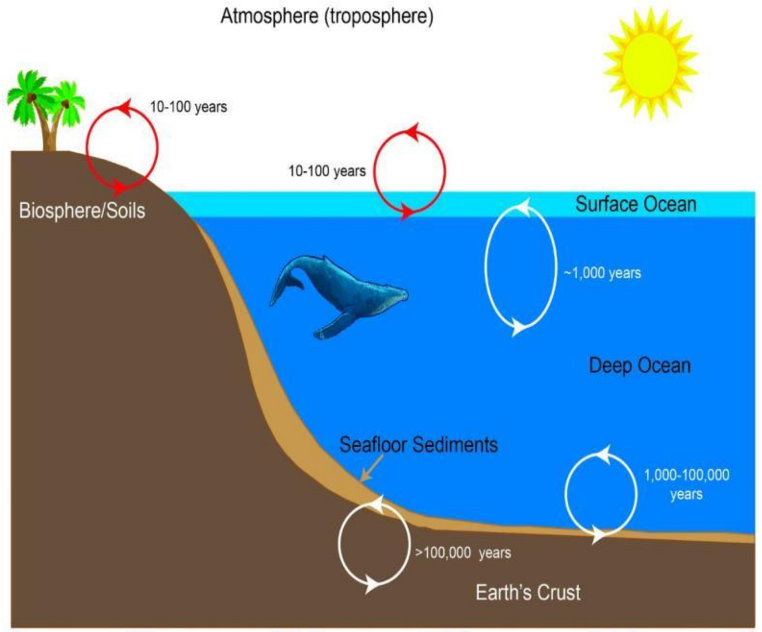


**Figure 44:** *Representation of circulation speed of carbon in several parts of the land, surface layers of the ocean, deep ocean and seafloor sediments – courtesy Phil Stoffer at Miracosta Education.*

In the open ocean, the thermocline acts as a barrier between the warm, well-mixed upper layer and the relatively static frigid deep dark waters to which the decayed bodies and shells of living things settle and are preserved or converted over aeons of pressure into limestone (including the Karst mountains strewn around the continents). Were it not for the active involvement of oceanic plants and animals, that would be the end of this story. However, every day, organisms, from the tiniest to the largest, together with wind and waves, help mix ocean waters. Plankton and the whales that feed on them engage in the "Greatest Migration on Earth" moving between the surface and the depths, stirring rate-limiting nutrients up from the ocean floor to other feed zooplankton, fish, and marine mammals including whales whose sinking carcasses eventually move significant amounts of "blue carbon" down into "cold storage". The processes by which carbon and minerals are moved from the atmosphere down into the ocean and down into the ocean's sediments is known as the Biological Pump.

The 'skin' at the top of the ocean comprises plant- and animal-driven processes that modulates the movement of *all gases and aerosols* between the oceans and atmosphere. Discovered only 60 years ago, a fingernail-thin film called the Surface Microlayer (or SML) comprises a distinctive mix of omega-3 phytoplankton lipids, surfactants, proteins, carbohydrates, marine life fragments, and living plankton that produce aerosols that loft into the wind, seed clouds, shade the oceans from direct sunlight and cause precipitation.

Unfortunately, these living plankton are being killed by toxic chemicals that are hundreds of times more concentrated in the SML than in the waters below because they adhere to hydrophobic plastic and carbon particles that float to the surface. This is arguably one of our biggest threats to climate stability. When the plankton die, the food chain collapses, the oceans lose oxygen, dead zones emerge. Cloud cover diminishes, sea ice and glaciers melt, more sun and inorganic $CO_2$ enters the water, the oceans acidify and the planet heats up in an accelerating and vicious cycle. (And those are only the *well-documented* consequences of SML destruction! There is much we don't know.)

Our oceans are a mosaic of distinct regional ecosystems, each with unique characteristics and ecological dynamics. The ocean also has a clear system of vertically stratified layers. The sun illuminates the upper 100 to 200 metres of the ocean. Here, the influence and interactions of atmosphere, wind, and sun are most pronounced. Temperature and salinity are relatively uniform due to continuous stirring by winds, waves and ocean life.

The mixing in the upper layers of the ocean happens in days, while in the deep oceans this occurs over millennia. Of the 38,000 Gt of carbon stored in the oceans, by far the greatest part is stored in the deep oceans and works as a vast long-term carbon store. During the Mesozoic period, some 100 million years ago, the amount of ocean-based life may have been as much as 35 times the current amount. Many of the world's extensive limestone formations were deposited during this time, especially in shallow marine environments. The deposition of limestone layers that would later become karst landscapes we now find around the world, is fossilised proof of the once incredibly productive living ocean ecosystems.

Vertical mixing, as in the thermohaline circulation of the Gulf Stream, also plays an important role in regulating weather and climate because it moves warm water downward and cold water upward, moderating surface temperatures that influence atmospheric conditions.

We would only need to regain a bit of that former power to increase ocean biology and sequester huge amounts of atmospheric carbon into the deep oceans where it would remain for millennia.

## The Thermohaline Ocean Circulation

To understand the oceans and their huge importance in balancing the Earth’s climate we need to take account of the thermohaline ocean circulation, often referred to as the ‘ocean conveyor belt’. It refers to a global system of deep-ocean currents driven by differences in temperature (thermo) and salinity (haline). This circulation has significant implications for global climate and marine ecosystems. Cold, saline waters in the polar regions are denser, causing them to sink to the deep ocean. As this water moves towards the equator, it warms up and becomes less dense, rising to the surface. This continuous cycle connects the world's oceans, distributing heat, nutrients, and gases across the planet. This circulation plays a vital role in regulating Earth's climate, as it helps redistribute heat from the equator to the poles. Disruption to the thermohaline circulation will have profound impacts on global weather patterns and sea levels. There is clear evidence that the conveyor belt is slowing down in the North-Atlantic and new evidence shows that the slowdown is underway also around Antarctica.

Should the conveyor belt collapse, all kinds of consequences would result. The North Atlantic region, including parts of Europe like the British Isles and Scandinavia, would experience a significant cooling, owing to the loss of the Gulf Stream's warming influence, while at the same time summer heat waves would increase. Rainfall patterns would be altered, potentially leading to drier conditions in Africa's Sahel region and increased rainfall in parts of Europe. Coastal regions, particularly the U.S. East Coast might be confronted by strong rising sea levels due to the gravitational effects associated with the Gulf Stream.

Marine ecosystems, especially in the North Atlantic, would be disrupted, affecting fisheries and their dependent communities. The formation and paths of tropical storms could also shift, potentially impacting regions such as the U.S. East Coast. While parts of the North Atlantic might cool, other regions could experience exacerbated global warming due to the lack of the conveyer's heat distribution. Additionally, the North Atlantic's capacity to absorb $CO_2$ could be altered, affecting the global carbon cycle. Similar, possibly even stronger effects would come from a slow down around the other pole. No studies have been made on how ocean biology and indeed the revival of ocean biology could have a mitigating effect on these dramatic changes.

## More About the Role of Plankton

Tiny plants called phytoplankton capture sunlight near the ocean surface. Through photosynthesis they convert water, atmospheric $CO_2$ nitrogen, and other elements into biomass. And when conditions are right, they multiply exponentially. Phytoplankton assimilate at least a third of the anthropogenic carbon dioxide emissions into the atmosphere. They produce most of the oxygen we breathe. Directly or indirectly, the energy and biomass captured by phytoplankton nourish virtually all ocean life, including the larger animals we call "sea food".

Phytoplankton and zooplankton (collectively, "plankton") also influence climate by influencing cloud formation. Cyanobacteria, coccolithophores, diatoms and dinoflagellate phytoplankton all produce dimethyl sulphide (DMS) as part of their metabolism. When DMS, which is volatile, is released into the atmosphere, it oxidises to sulphur dioxide which nucleates water vapour, stimulates cloud formation and thereby increases the reflection of sunlight out to space. The cooling under the newly-formed cloud is likely to cause some turbulence in the surface waters, resulting in some upwelling of essential nutrients.

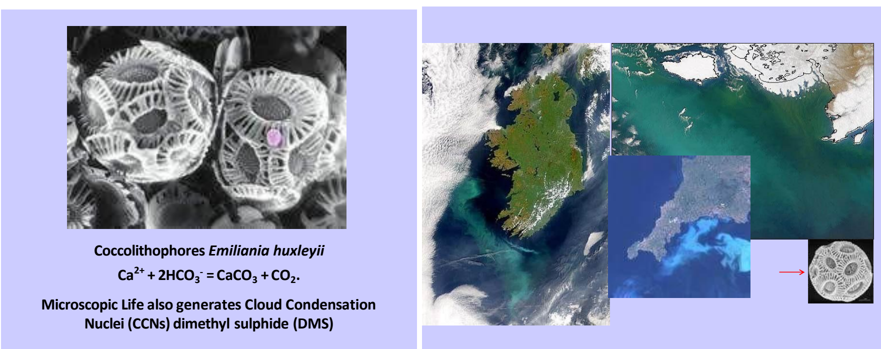


**Figure 45:** *Life in the oceans, e.g. Coccolithophores, plays a significant role in the flux of carbon, including its deposition at the bottom of the sea – Plymouth Marine Biological Institute.*

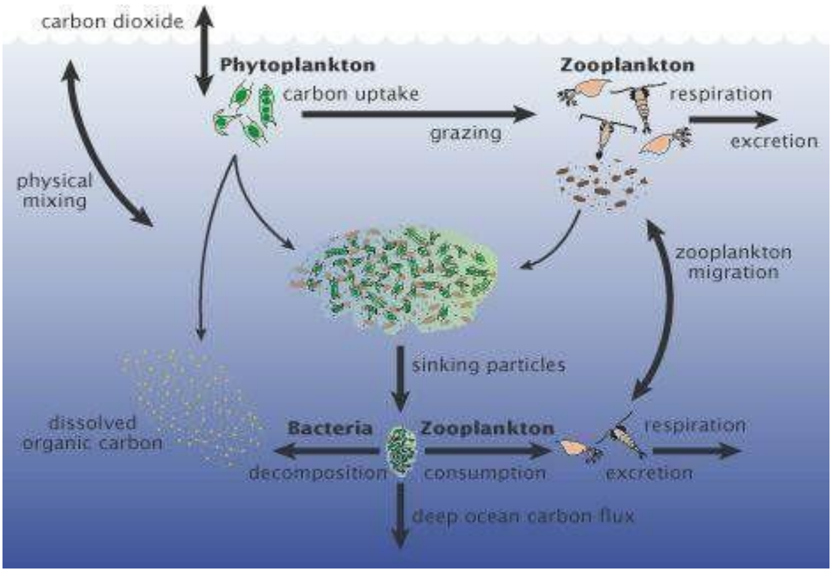


**Figure 46:** *The oceanic carbon cycle*

Plankton sequestrates considerable atmospheric $CO_2$, turning it into living carbon which, on dying, sinks. A crucial part of the ocean's carbon cycle is the production by zooplankton of countless microscopic shells made of calcium carbonate. Some of these shells sink to the ocean floor, store carbon and eventually are transformed into limestone. Other living organisms use calcium carbonate to form coral reefs. Like the air we breathe, and the climates we enjoy, landscapes and islands around the world are created and maintained by living systems in a dynamic balance that has evolved over millions of years. The large amounts of $CO_2$ added to the atmosphere through the burning of fossil fuels has now unbalanced the carbon cycle.

## Coastal Zones

Whereas life in the open oceans is limited by nutrient deficiencies, coastal regions especially in the tropic and temperate latitudes are often overwhelmed by industrial development and by fertilisers, pesticides, herbicides, plastics and soot that move into the oceans via terrestrial and atmospheric rivers and ocean currents. Land management practices that reduce these unwanted impacts are discussed in our Chapters on *Land, and Agriculture, Cities etc.* Here we focus on strategies and tactics for rebuilding coastal zones and using them as key tools in the restoration of both land and water cycles.

Large parts of the living ocean are in a very bad, even critical condition. Around the world we see more and more hypoxic and even complete dead zones.

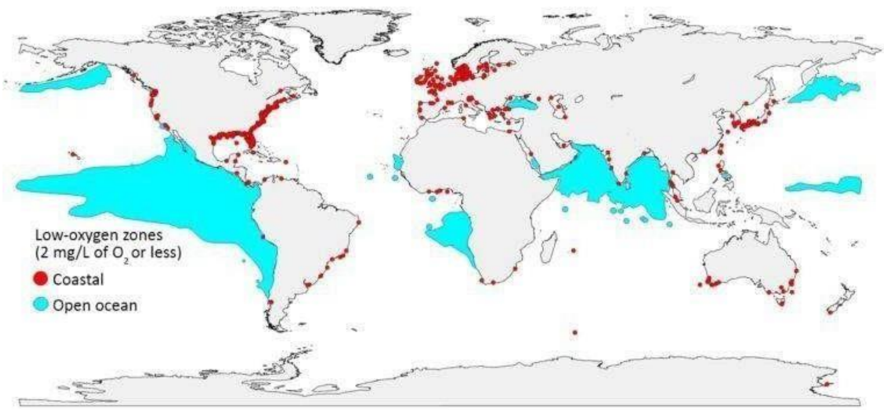


**Figure 47:** *Image: UN Intergovernmental Oceanographic Commission GO2NE working group*

Reviving the oceans and coastal marine ecosystems everywhere is crucial in our fight against climate change. It is time for systematic therapeutic action all over the world, combined with accelerated research to assess strategies and elucidate processes. When conditions are right, oceanic populations can increase rapidly. Let's make them right.

## The Grave Danger of Ocean Acidification

Everybody has heard of ocean acidification, but the danger it poses to current life on Earth is not well understood. Ocean acidification is a consequence of the oceans absorbing significant amounts of carbon dioxide ($CO_2$) from the atmosphere. It poses numerous threats to marine life and ecosystems. As the seawater becomes more acidic, the availability of carbonate ions, vital for marine creatures like corals, molluscs, and some types of plankton to build their calcium carbonate shells and skeletons, decreases. This leads to thinner, more fragile shells and weakened coral structures, reducing their resilience to other environmental stressors. Coral reefs, often dubbed the rainforests of the sea, are particularly vulnerable; their decline results in the loss of habitat and breeding grounds for many marine species. Additionally, fish and other marine organisms might experience altered behaviour and disrupted physiological processes due to changes in the chemistry of the water. These cascading effects can compromise the stability of marine food webs, threatening fisheries and the livelihoods of millions of people dependent on the ocean. It is clear that we are approaching thresholds in acidification after which a tipping point involving the survival of ocean life becomes unstoppable, at time scales relevant to human survival.

This picture shows that the pH threshold is at around 7.95 and we are approaching this fast. Addressing climate change involves more than just carbon reduction, with oceanic pH predicted to fall to a critical level by 2045 even if net-zero carbon emissions are achieved soon. Once this happens, the oceans will start to outgas $CO_2$ faster and atmospheric $CO_2$ can no longer be controlled. Evident signs of marine ecosystem collapse can be seen in more and more regions, and is well-documented in the case of the Marmaris Sea. Ocean acidification can reduce the ocean's capacity to absorb $CO_2$, accelerating the rate of global warming.

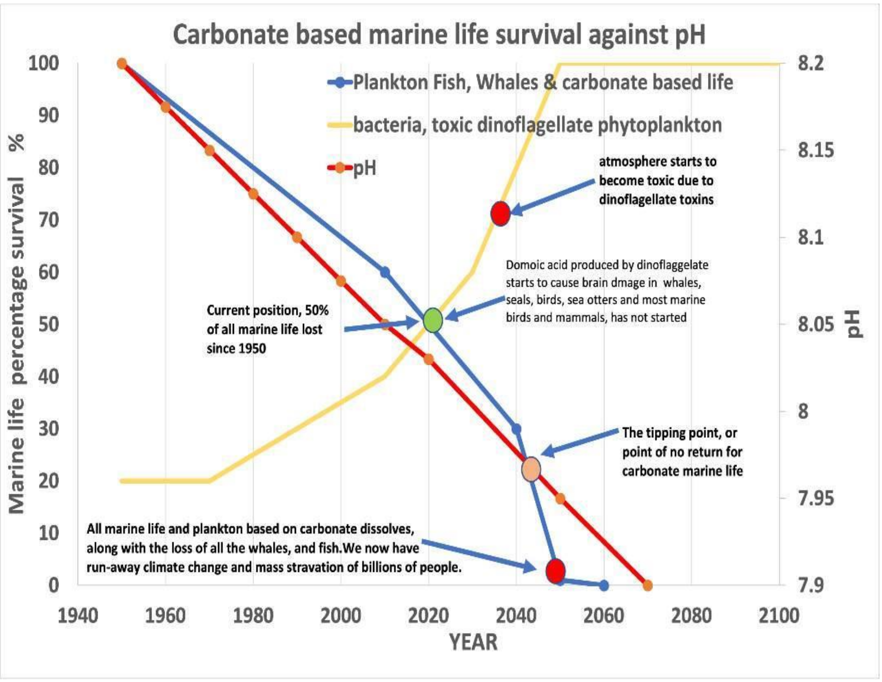


***Figure 48:*** *pH changes over time - courtesy Goes Foundation*

## A Framework for Action

Although there is much we do not know, we know enough to identify essential processes and necessary steps to reduce threats, increase productivity, restore climate, and regenerate abundance. We know how to protect and regrow the ecosystems that turn $CO_2$ into living carbon which provides food and oxygen and climate regulation rather than into atmospheric carbon (which captures heat from sunlight and heats the planets). In principle, we must stop poisoning ocean life, we must stop our trawling of the ocean floor, destroying all life there and we must stop overfishing.

Ocean primary biomass production is currently estimated at 33 Gt of carbon per year, which translates to 118 Gt $CO_2$ but this has been declining. With the revitalization of oceans, we can substantially increase the biomass, not only delivering carbon sequestration in both living and dead carbon, but also bring about a tenfold increase in zooplankton and a 1 kg per 100 kg increase in fish and marine mammals.

But the cooling effects would be much greater than that, translating into additional cloud formation, precipitation and thermal radiation of heat into outer space. In combination with coastal marine ecosystem and coastal land ecosystem restoration (kelp, reefs, mangroves, wetlands), the amount of precipitation in coastal areas can be increased, and the severity of hurricanes decreased.

## Call to Action

### Priority list of actions to be taken for the health of the oceans

1. Restore the SML by substantially reducing the amount of waste water from land that runs off into the oceans, including plastics, chemo-nutrients and pesticides from industrial food production. The restoration of the Sea Surface Microlayer (SML) is critical to the health of the oceans. Almost 80 per cent of the human population has no municipal wastewater treatment and therefore flushes waste directly out to sea. New techniques are now being deployed that can remove the toxins within months from dead zones.
2. Protect and revive coastal ecosystems that serve as nurseries for life both on land and in the oceans. This includes protection and revival of coral reefs, sea grasses, kelp forests, oyster banks, mangroves, deltas, estuaries and coastal lagoons in a way that supports those populations making a living through sustainable harvesting of those coastal ecosystems. Included in this must be measures to reduce eutrophication and toxification from agricultural, industrial and sewage runoff.
3. Replenish fish stocks and store carbon in biomass by

    - imposing moratoria and quotas on fishing in large parts of the oceans.

- creating and expand continent-sized marine parks in mid-oceans so that they become no-go areas for fishing.
- Enforcing bans on large scale drift net and dragnet fishing.

These measures will increase fishing yields in adjoining areas, while increasing global food supplies.

4. Explore large scale plankton restoration through replenishment of rate-limiting micro-nutrients. For example, phytoplankton blooms with the help of iron oxide distributions in the now ''desertified'' parts of the oceans. This has the potential to offset a large part of anthropogenic greenhouse gases.
5. Protect and revive whale populations. All loopholes in the International Convention for the Regulation of Whaling must be closed, and breeding grounds protected. Whales have long lives and reproduce slowly, which can make them vulnerable to overexploitation. The widespread and systematic hunting of whales for their blubber, oil, and other products during the peak of commercial whaling led to a significant decline in many whale populations. Some species, such as the North Atlantic right whale, were particularly hard-hit and came dangerously close to extinction. Efforts to protect whales and regulate whaling activities started in the 20th century. The International Whaling Commission (IWC) was established in 1946 with the goal of conserving whales and managing whaling activities sustainably. Various moratoriums on whaling have been put in place, and some whale populations have shown signs of recovery due to these conservation efforts. But this is not enough. Not only do we need a total ban on whale hunting, we also must restore the health of the oceans to feed these majestic creatures.
6. Replace toxic chemicals with safer alternatives. Ban single-use plastics and keep microfibers out of wastewater by banning plastic-based fabrics or developing filtration systems that can reliably remove them. Cosmetics contain some of the most toxic of chemicals such as oxybenzone sunscreen and microplastics. The packaging also tends to be toxic. Anything toxic to nature

will also be toxic to people. 20,000 tonnes of oxybenzone is used in sunscreen and cosmetics every year. Around 70,000 tonnes would wipe out all the coral reefs and most life in the world's oceans. Car and lorry tyres are horribly toxic, the microplastic washes off the roads when it rains and most of it enters rivers and then the seas and oceans. There are non-toxic or less toxic options that just need to be implemented.

7. Prevent massive marine habitat destruction by strictly regulating deep sea mining Underwater excavation would be profoundly harmful; other techniques such as lifting nodules off the seafloor may be workable.
8. Work out a detailed plan for marine restoration around the world based on blue carbon finance and with business models that make investment in regeneration profitable. Our network has a portfolio of working projects with different impacts on reviving biodiversity, cleaning water qualities, eradicating toxic blooms and bringing back fish stock and other marine edible produce that can be harvested in a sustainable way, while reviving the biology of the area.

Reviving the oceans is one of the key pillars to cool climate chaos fast. We need a world- wide programme carried out by all countries to carry out ocean repair now and with that revive life in the oceans, to restore fish stocks and replenish other marine food sources. By that we will sequester huge amounts of $CO_2$ and will increase cloud cover, thereby cooling the Earth. These measures together will help the vertical mixing of ocean waters, the fast revival of ocean biology and very likely will have beneficial effects on sea ice and ocean circulations.

# Chapter 11
# Substantially Sequestering Atmospheric Carbon

According to the Intergovernmental Panel on Climate Change (IPCC), global terrestrial ecosystems currently store approximately 3,100 gigatonnes (Gt) of carbon, with forests alone accounting for about 2,400 Gt. The total amount of atmospheric carbon is estimated at 3,200 Gt and the total amount of carbon in the oceans is estimated at 38,000 Gt, which includes more than a thousand GT of so-called methane clathrates in the Arctic Ocean continental shelf. In the great terrestrial permafrost areas of the Northern hemisphere maybe as much as 1500 Gt is buried.

*Note: an oft-made mistake is to confuse carbon with $CO_2$. The weight of carbon in a molecule is about 27 percent, the rest is oxygen. A ton of atmospheric carbon in $CO_2$ translates to 3.66 tons of $CO_2$.*

On land, forests are some of the most effective carbon sinks, with mature forests sequestering more carbon than younger or disturbed forests. Healthy mature rainforests can hold several hundreds of tons of carbon per hectare in their soils, root systems and above ground biomass, with temperate and boreal forests roughly half that amount, all depending on local circumstances.

Mature tropical forests can sequester up to five tons of carbon per hectare per year, while temperate and boreal forests can sequester up to two to three tons per hectare per year. Destroyed forests that are regenerating naturally or with help through reforestation or assisted natural regeneration can sequester even more carbon in their juvenile phase after which the sequestration capacity slows down.

Grasslands and savannas have a lower per annum sequestration capacity but through their deep root systems can hold much larger carbon amounts over long periods of time. Just the top thirty centimetre of soil in a prairie can hold as much as thirty tons of carbon, while the root systems can penetrate several metres. These systems have a sequestration capacity of anywhere from half a ton to two tons per hectare per year.

Wetlands, such as marshes and swamps, can sequester large amounts of carbon in their soils, but the exact amount varies depending on factors such as water levels, soil type, and plant species. The IPCC estimates that wetlands can sequester up to one metric ton of carbon per hectare per year.

Over the past few centuries, the oceans have absorbed and stored a significant amount of carbon dioxide from human activities, such as burning fossil fuels and deforestation. It's estimated that since the industrial revolution, the oceans have absorbed approximately 25- 30 per cent of the carbon dioxide emissions from human activities. This has led to increased acidity in the oceans, which can have negative impacts on marine life. The total carbon sequestration capacity of the oceans is estimated by the IPCC at around 2.5 Gt per year but there are reasons to believe that this is a gross underestimate. It is likely that both the open oceans and especially the coastal marine ecosystems both have huge additional sequestration capacity as well as mechanisms through which they regulate the acidity of the oceans. It is likely that we have severely diminished those capacities through ocean pollution, destruction and depletion. To stabilize the climate as well as the global food production capacity it is of the highest priority to research the potential of assisted natural regeneration of ocean biomes.

## Global Warming caused by Atmospheric Carbon and Water Vapor

Greenhouse gases keep the Earth habitable. Without greenhouse gases, such as carbon dioxide, methane and water vapour, the Earth would be about 33°C (59°F) colder on average than it is today, at some -18°C or around 0°F. This is because greenhouse gases trap heat in the atmosphere, which helps to keep the Earth's temperature within a range that is habitable for life as we know it.

While greenhouse gases are necessary for life on Earth, the buildup of these gases in the atmosphere due to human activities, such as burning fossil fuels and deforestation, is causing the Earth's temperature to rise at an unprecedented rate, leading to climate change and other environmental impacts.

The exact climate sensitivity of $CO_2$ is not well known and is dependent on how much solar radiation is transformed into latent heat (in the form of the evaporation of liquid water) or sensible heat (the increase of temperature through the increased movement of gas molecules in the atmosphere, which in turn is amplified by the greenhouse gases). This parameter is defined as the amount of warming that can be expected from a doubling of $CO_2$ concentrations in the atmosphere from 280 ppm to 560 ppm. The IPCC Fifth Assessment Report estimated the range of climate sensitivity to be between 1.5°C to 4.5°C.

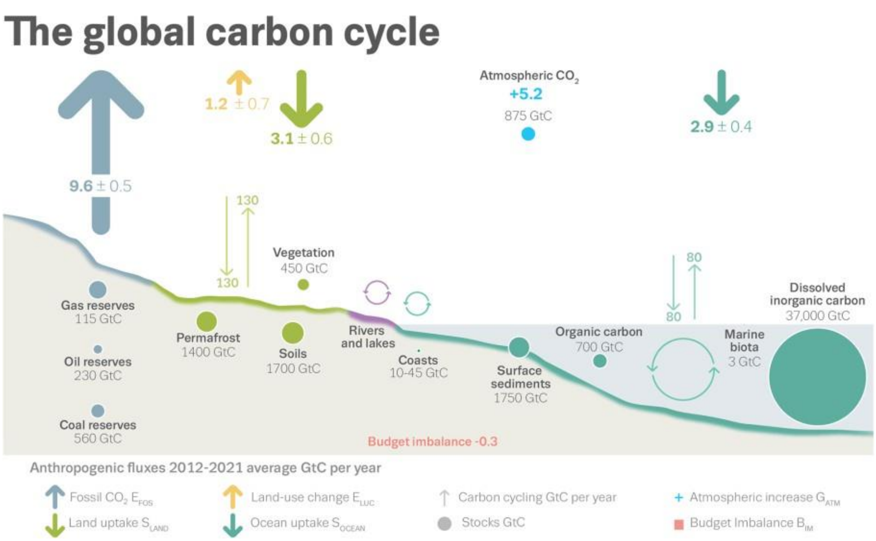


**Figure 49:** *The Global Carbon Cycle and where all the carbon is. https://doi.org/10.5194/essd-14-4811-2022 - Courtesy authors under the Creative Commons Attribution 4.0 License.*

## Consequences

Next to land use change and the destruction of the cooling capacity of ecosystems, the increase of atmospheric carbon is the second largest cause of increasing global temperatures and has a large impact on dehydration of land. Once temperatures shoot past 40°C, photosynthesis stops which is a part of the crucial regulating mechanism of terrestrial biomes, so beyond this temperature they shut down and if this happens long enough, they die off.

## Solutions & Actions

Reducing the emissions of greenhouse gases, in particular carbon dioxide and methane, will undoubtedly help to regulate the global temperature but such reductions are of less direct influence in mitigating extreme weather than could be derived from the regeneration of ecosystems.

The restoration of forests and other ecosystems has the potential to sequester a significant amount of atmospheric $CO_2$ globally. Several calculations have shown that we can offset global $CO_2$ emissions by protecting remaining forests, restoring degraded forests and other ecosystems. A 2017 US National Academy study estimated that natural climate solutions, which included the restoration of forests and other ecosystems, could potentially sequester up to 23.8 billion metric tons of $CO_2$ per year, which is equivalent to halting global fossil fuel emissions.

The oceans are one of the largest carbon sinks on the planet, and healthy ocean ecosystems can help to absorb and store much more carbon than is currently accounted for. An increase in the rate and extent of photosynthesis by marine phytoplankton, which convert carbon dioxide from the atmosphere into organic carbon has yet to be properly evaluated through experimentation. When these organisms die, their bodies sink to the seafloor, taking the carbon with them and effectively sequestering it for hundreds or even millions of years. As they do so, they also reduce ocean acidification by sequestering $CO_2$ in calcium carbonate in the form of shells and other organic materials produced by marine organisms.

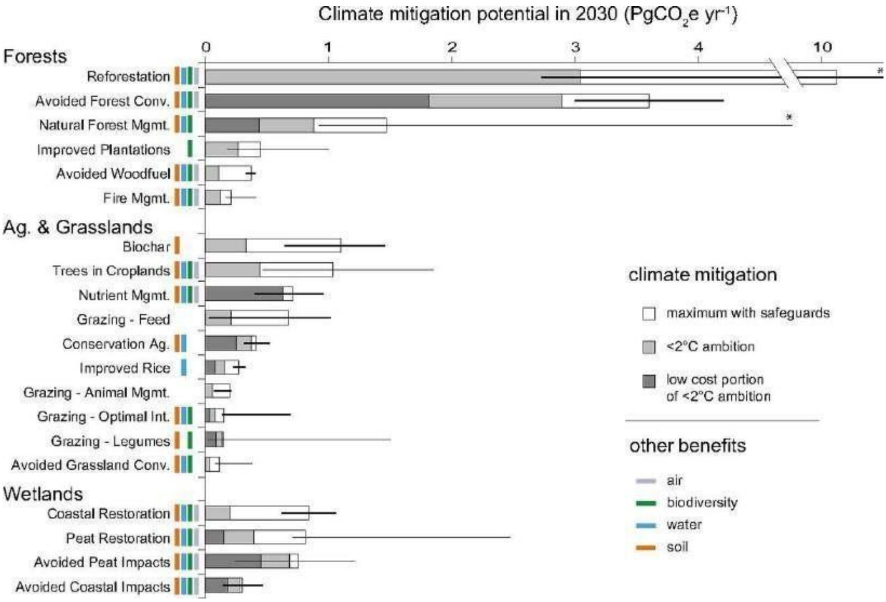


**Figure 50:** *From Natural climate solutions, where we can bury carbon and how much - courtesy PNAS*

While we are very clear in this book that the increase of atmospheric $CO_2$ from fossil fuel burning is one of the causes of global warming, the main cause results from ecosystem degeneration and destruction. Such degeneration leads to greenhouse gas emissions, but more importantly, as we have pointed out in previous chapters, it has led to the loss of cooling mechanisms associated with a serious reduction globally in short water cycles.

Meanwhile, regeneration of those essential ecosystems, like tropical rainforests, will both renew and rejuvenate small water cycles and increase the safe storage of $CO_2$ in soils and biomass.

## Trophic Rewilding can Expand Natural Climate Solutions

Undoubtedly, animals have a role to play in the regeneration of ecosystems. Plants need carbon dioxide in the atmosphere for them to be able to photosynthesise and the role of animals in effecting a rapid turn-around of carbon derived from vegetation is part of the balancing act which comes with biodiversity. Animating the carbon cycle through trophic rewilding is therefore an essential part of regeneration when pursued in the right landscape, for instance the prairies of the Mid-West which harboured the buffalo.

Environmental science has yet to catch up with the climate-associated benefits of trophic rewilding, especially with respect to the quantification of carbon cycling and the benefits to climate of such naturally evolved associations. We need to change our mindset concerning the potential benefits of rewilding and bring in policies that acknowledge that the restoration and conservation of animal species has potential to be an instrumental part of natural climate solutions. There is some urgency on both fronts because we are losing populations of many animal species at the very time that we are discovering the degree to which their functioning in ecosystems can impact carbon capture and storage. Thus, ignoring their impacts leads to missed opportunities to enhance the scope, spatial extent and range of ecosystems that can be enlisted to help hold climate warming to within 1.5°C.

# Chapter 12
# Can we Slow and Even Reverse Sea Level Rise?

Sea level rise and fall has happened throughout the history of the planet and ecosystems adjusted accordingly. With the current huge human population and critical infrastructures such as cities, transport facilities and critical food growing areas very near to sea shores, the impacts of even small sea-level rises can have dramatic consequences. Since the start of the industrial revolution sea levels have risen on average around 20 centimetres or 8 inches according to NOAA, the National Oceanic and Atmospheric Administration. The high likelihood is that near future sea level rise will accelerate and be measured in metres rather than centimetres. The current IPCC forecast of 1.1 metre by 2100 is a scenario that does not include the possibilities of sudden collapse of large parts of ice sheets, particularly in West Antarctica and Greenland.

From a management perspective we need to take into account multi-metre sea level rise (SLR) caused by non-linear events such as the accelerated calving of the Thwaites glacier. Plans to deal with SLR should take into account as much as a 2 metre-rise by 2100. If we should fail to cool the climate then sea-level rises of ten metres or more could follow in the centuries to come. If we were to fail to deal with global warming during the following decades, then, in all likelihood, in the not-so-distant future, our societies will collapse and our great cities be no more than archaeological ruins. Only by reversing the warming trends of several degrees forecasted by the end of this century will we be able to continue to live in highly complex globally integrated human societies, with at least 8 billion people. But our future societies, for survival, will have to function in a completely different way from those we now experience. They will have to be integrated with a healthy environment, encompassing properly functioning ecosystems.

In such future societies, digital technology will be the main form of interaction and foods and other goods will be sourced regionally. If we are not able to slow and stop the rise of sea levels, it is likely that floating communities will be found all around the edges of the land masses. But let's first investigate if something can be done about Sea Level Rise (SLR). This chapter is highly speculative as we enter into a realm where much research is needed. While the authors are very confident about the main theses of this book, how to reverse climate chaos fast and cool the planet, what you find in this chapter is meant as a way to trigger a conversation about solutions, rather than give real recipes to counter this huge challenge.

## Main Causes of Sea Level Rise

Sea Level Rise (SLR) happens all around the world, and is caused by a combination of global and local factors. The largest global contributor so far has been the thermal expansion of water as the temperature rises, accounting for less than half of SLR during the last two hundred years and has been estimated at 1.3 mm per year, taking into account that it has risen by 3.5 mm per year in the period of 1993-2010. In addition, the melting of glaciers and ice caps, including those in Antarctica, Greenland, and high mountain glaciers around the world such as the Rocky Mountains, Andes, and the so-called Third Pole (the Himalayas and Hindu Kush), has significantly contributed to rising sea levels. Another important factor is the dehydration of land through changes in land use and the pumping of aquifers mainly for agricultural purposes.

Local sea level changes can also be significant, driven by shifts in ocean circulation patterns. For instance, the slowdown of the Atlantic Meridional Overturning Circulation (AMOC) has led to increased sea level rise along parts of the East coast of the USA.

While not technically contributing to sea level rise, land subsidence caused by human activities like groundwater extraction and the construction of heavy buildings has increased coastal inundations.

Dramatic examples of this phenomenon can be found in megacities such as Jakarta and Lagos.

Coastal erosion due to the destruction of ecosystems both on land and in shallow waters have increased the vulnerability to the encroachment of the sea as well. Especially the removal of mangroves, the degradation of coral reefs, the mining of sands for construction and the removal of wetlands, which buffer the force of storm tides and waves, have been detrimental to coastal security.

## Consequences

The rate of global sea level rise is accelerating: it has more than doubled from 1.4 mm (0.06 inch) (1.4 millimetres) per year throughout most of the twentieth century to 3.6 millimetres (0.14 inch) per year from 2006–2015.

The Small Island Nations are the first in the firing line of SLR. A large number of them consist of coral islands and volcanic islands. Some, such as the Maldives, should theoretically be able to keep their heads above water if SLR took place slowly enough and sea water temperatures were low enough to keep coral reefs from bleaching plus the assumption that their reefs were healthy enough to keep up with the rising waters. Sadly, in reality, that is not the case. Meanwhile experts around the world are coming up with techniques that can help to slow down the impacts and even help to shore up coast lines. But on average these techniques are not enough to offset the current rate of SLR. The highest SLR scenarios in the chart above include the IPCC modelling of the potential for sudden collapse of large glaciers on Greenland and the Antarctic ice sheets, but there is considerable uncertainty about these scenarios and the latest research shows that these might well be conservative estimates.

The buttressing of the land-based glaciers on Antarctica depends a lot on the rate of floating sea ice, which is retreating in 2023 at a much faster pace than expected.

## The Consequences of Sea-level Rise

The first and most obvious one is:

- Flooding, which can lead to loss of land, infrastructure, property and the displacement of people. Major population centres are at risk from SLR. The IPCC indicates that 1 metre of sea level rise would directly affect 187 million people around the world, but again this number is far too conservative. A *Guardian* article from 2021 puts it at 410 million, which is probably still an underestimate. But there are more effects such as coastal erosion and saltwater intrusion affecting agriculture and drinking water availability.
- Second round effects are displacement of people, sometimes hidden from the public eye. Salt infiltration in places like the Nile delta, Mekong and in Bangladesh have caused migration to the capital cities without being noticed immediately as caused by sea level rise.
- Other second round effects which have been mapped in a fragmented way are the changes it would make to marine and coastal ecosystems and changes in ocean currents with additional climatic effects.

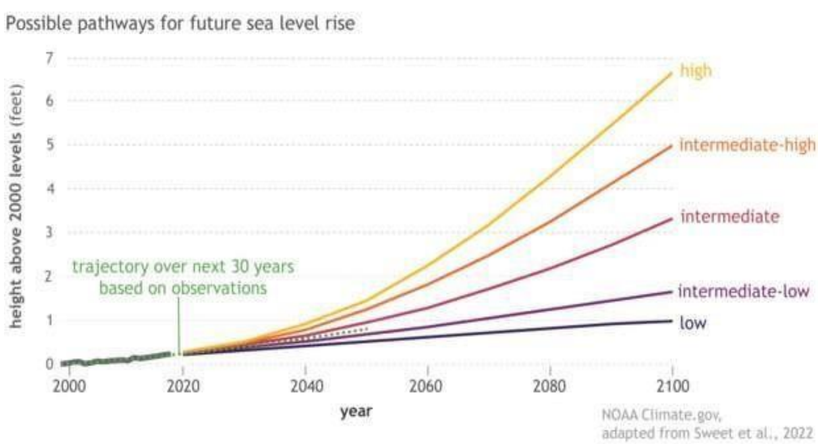


**Figure 51:** *Possible Pathways for future sea level rise. Courtesy NOAA, Sweet 1 foot = 304.8 mm, 7 feet = 2.13 metre.*

## Solutions

The most obvious solution to SLR rise is to **slow, stop and reverse the warming up of the planet**. While this, at the current state of knowledge, will not avoid multi-metre sea level rise, it can slow the pace of it happening. Once we are able to really cool the planet, we will also see the shrinking effect of cooling seawater but this will all be very slow.

Minor solutions that will be in the order of magnitude of centimetres of Sea Level Lowering (SLL) are the rehydration of the land masses in several ways. If done in the right way, the main positive effect would be the increase of biological activity on land and the reversal of water crises for agricultural, industrial purposes and of course drinking water, while bringing the temperature of the planet down.

## Improving the Health of Coastal Marine Ecosystems improves Coastal Resilience

Mangroves, healthy coral reefs and other coastal ecosystems such as kelp forests and coastal lagoons and wetlands serve as indispensable guardians of coastlines against the adverse impacts of sea-level rise. These natural barriers, with their inherent characteristics, provide a multifaceted defence mechanism against the onslaught of the rising seas. One of their most prominent roles is in mitigating the destructive effects of storm surges and high-energy waves. Coral reefs, with their intricate and robust structures, act as underwater ramparts, dissipating wave energy before it reaches the shore. Similarly, the sprawling, dense root systems of mangrove forests absorb wave energy, considerably reducing the velocity and force of water. This crucial function significantly reduces coastal erosion and potential devastation during storms. They have even proven their important role in reducing the damage of incoming tsunamis.

In addition to their role as a physical barrier, mangroves further contribute to coastal protection by trapping sediments in their labyrinthine root systems. Over time, the accumulated sediments contribute to building and stabilising the land, in turn raising the elevation of coastal areas. In certain locations, this mechanism could potentially keep pace with sea-level rise, serving as a counteracting force. This also goes for coral reefs and other coastal and marine life. Salt marshes, tidal flats, seagrass meadows and indirectly kelp forests all help trap and stabilise sediment, potentially contributing to land formation and coastal protection. Not just mangroves but other halophytes can speed up these processes as well and help establish food production in these areas. Designing coastal protection projects should take these elements of ecosystem restoration into consideration. While these processes would be overwhelmed by multi-metre sea level rise, they can mitigate the effects on coastlines if we are able to cool the planet before this happens.

Beyond the immediate shoreline defence, both mangroves and coral reefs are significant carbon sinks. By sequestering large amounts of carbon dioxide from the atmosphere, they help mitigate climate change, indirectly contributing to the reduction of sea-level rise. Their role in this global endeavour showcases the interconnectedness of ecological systems and their broader implications for climate change.

## A Look at One Example of Marine Ecosystem Restoration

Oysters and mussels are natural filter feeders and, with an adult oyster's capability to clean up to 200 litres of water daily, they significantly reduce suspended particles, algae, and excess nutrients from the water. This activity helps in controlling harmful algal blooms, which arise from nutrient overloads and can be detrimental to both marine life and humans. Beyond filtration, oysters and mussels contribute to nutrient recycling, particularly aiding in the denitrification process where bacteria in the oyster beds convert waste, rich in nitrogen, into harmless nitrogen gas. These beds also serve as a sanctuary for diverse marine life, offering habitats to small fish, crustaceans, and other invertebrates, thus bolstering marine biodiversity. On the coastal front, oyster reefs function as natural buffers, tempering the force of waves, preventing erosion, safeguarding marshlands, and attenuating the impact of storm surges. Their role in improving water clarity also indirectly promotes seagrass growth, another ecosystem crucial for marine health.

Around 85% of global oyster reefs and mussel beds have been lost, marking these habitats as some of the most severely affected in the marine environment. This decline has been caused by overharvesting, pollution from industrial activities which also has led to large die- offs as degraded beds became more susceptible to diseases. The direct habitat destruction from coastal development, from dredging, and changes in estuary conditions, as well as rising sea temperatures and ocean acidification, have compounded the challenges facing oysters and mussels. Considering their ecological and economic significance, global initiatives are now focusing on oyster reef restoration to recapture their benefits, which in turn would help revive ocean biology, such as kelp forest and sea grass meadows which thrive in clean water and cool the planet. Imagine if we could recreate the vast, sometimes thousands of kilometres long oyster reefs and mussel beds that once straggled the coast lines of places like Southern Australia, but have largely disappeared.

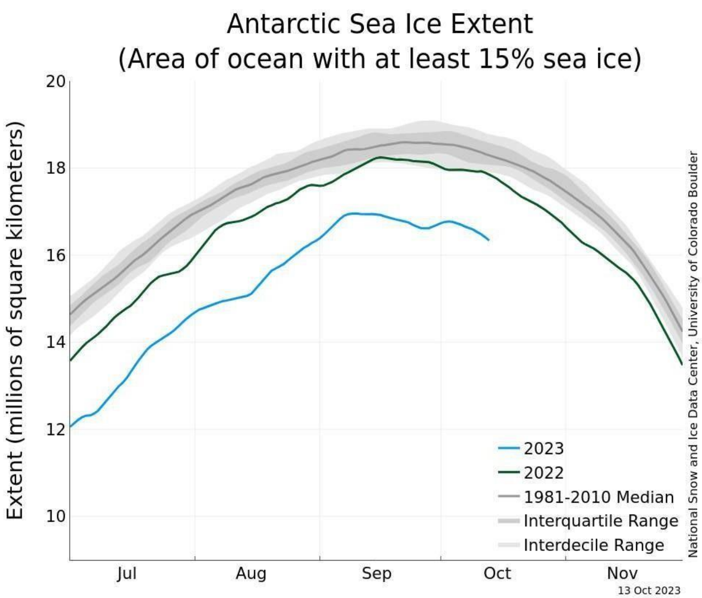


**Figure 52:** *Antarctica Sea Ice, 2023. Courtesy National Snow and Ice Data Center, University of Colorado Boulder*

**Figure 53:** *Oyster bed on the rock under the sunlight – Photo Aiyoshi/Shutterstock*

## Integrated Regional Multi Ecosystem Regeneration to Offset Sea Level Rise

The integrated combination of coastal ecosystem restoration combines emerging science with time-tested Indigenous and grassroots knowledge to deploy nature-based solutions. For coastal regions the integrated plans of estuary management, oyster and mussel beds, managing and treatment of river runoff, mangrove restoration, and so on, can help slow down the encroachment of the sea considerably in many places, buying those areas time to transition to a more sustainable coastal land and water use in line with rising sea levels.

## Reversing Sea Level Rise? You Must be Kidding!

All water on land has arrived through precipitation, and the question is, can we increase precipitation on the world's ice sheets and mountain chains fast enough to counter melting in the next decades and centuries?

Emerging science shows that all healthy biomes interact with water and the atmosphere to create clouds and rain and balance the local climate, cooling and creating the conditions for life to thrive. considerable research for additional action needs to be done with regards to the atmospheric hydrology of the planet because reversing SLR, apart from cooling the planet, would mean that we would have to increase precipitation substantially on the ice sheets and mountain chains. That sounds more far-fetched than it is because in other eras those ice sheets were formed by snowfall, which was connected to atmospheric rivers dumping their precipitation in those areas.

The hypothesis is that through increased biological activities of ecosystems, particularly the great forests but also the marine based ecosystems, it is possible to increase land-based precipitation, which means increasing both quantity and albedo of those systems slowing or even reversing a net melt of these large ice masses. Maybe rich algae blooms were the main rainmakers responsible for the formation of the southern ice sheets, hence activating additional algae blooms in the Southern Ocean could trigger increased cloud cover and precipitation on Antarctica, increasing the ice pack, helping to cool locally and globally, thus reversing SLR. A bloom in phytoplankton increases the vertical mixing of the temperature layered oceans, hence bringing cooler water to the surface, which reinforces the blooms. In addition, the subsequent cooling will have a strengthening effect on the Antarctic jet stream, cooling that continent even faster, which increases the area covered by the floating ice pack. The larger reflective surface will then add to the cooling.

Certainly, the cooling effect of regenerating polar-life should be tested with desk research and real experiments. We know how cost-efficient and fast algae blooms can be triggered through ocean fertilisation with iron dust and other elements. The increase in zooplankton following the increase of phytoplankton would help the vertical mixing of the ocean waters by an explosive increase in copepods which would again feed the other creatures in the marine food chain, including seabirds and sea mammals such as whales and seals. Their mixing and increase of the nutrient cycles could fast become a positive feedback loop. Some evidence comes from a record salmon run in Russia's rivers after the eruption of a volcano.

Some people suggest considering engineering to grow ice, especially with regards to the Arctic and vulnerable glaciers that provide people with drinking water. The spraying of water in the air during cold periods to create ice is what has been done for ski slopes for a long time and oil companies have created ice islands for their drilling activities. Even if this would work locally, these techniques cannot be more than marginal, but at very strategic places, such as glaciers that provide drinking water to cities like in the high Andes, we should not exclude the possibility of them having some effect.

Quite often people propose technological solutions to climate change, usually called geo- engineering. While the authors of this book do not exclude the possibilities that technology can bring to the table, we envisage several major objections that need to be overcome first: one is the size of the problem. Human activity for sure is changing the climate but that has been by all of us everywhere over a long period of time. Applying new technology bounces up against the sheer scale and complexity of the problem. Some of the proposed technological solutions, like carbon capture and storage (CCS) or certain geoengineering methods, have not yet been proven to work on the needed scale and might have unintended side effects. Economic constraints are another challenge, as many potential solutions require vast investments and require more extraction from the Earth. As a rule of thumb, we must first look to nature and the biosphere to see how life itself, over a period of billions of years, has solved environmental challenges. Biomimicry should be the first guideline. Especially carbon capture and storage (CCS) is, in our understanding, a complete waste of time and money as the price is far too high. It burdens the Earth with additional resource use and, compared to ecological restoration and the increase of photosynthetic biomass which does this much more elegantly, it has no co-benefits except for industries that build them.

Moreover, climate change is intertwined with other systems. Addressing only the atmospheric component might not solve related challenges like ocean acidification or biodiversity loss. And even when effective technologies are identified, there can be significant delays in developing, testing, and implementing them at the necessary scale. That said, some human scale interventions at crucial points in the landscape might have outsized effects that potentially makes them effective, for instance, employing methods to slow the melting of glaciers crucial to water supplies in places like the high Andes and Himalayas.

## Call to Action

This "Living Earth" perspective enables each of us to address local challenges and be a critical part of global climate solutions. The issue of SLR ties in completely with the cooling of the planet and increasing the biotic pump function of the great forests and other healthy ecosystems around the world. Typical elements of an overall plan that might have considerable effects are the rapid increase of phytoplankton blooms to draw down carbon and the increase of ocean biology, ranging from phytoplankton and zooplankton to whale populations, to break through the temperature stratification of the oceans and help with the nutrient cycles between the deep and shallow ocean layers.

Meanwhile, all kinds of locally adaptive and locally mitigating effects can be achieved, such as the coastal erosion repair through smart measures like mangrove and coral reef protection and forms of engineering designed to intentionally increase silting up of sandbanks and beaches. Adaptive measures such as the construction of sea barriers are extremely costly and effective only within certain limits. Moreover, such measures are highly localised and do not address the overall consequences of SLR. In conclusion, such efforts are, on the whole, losing battles unless we are able to cool the planet fast and with that reverse the expansion of ocean water and the undermining melting of the ice shelves.

## Investments and Benefits

Cooling the planet is the best way to slow Sea Level Rise. The protection of coastal cities, infrastructure and food production areas together hold a considerable part of the total 1500 trillion-dollar global asset value. Cooling the planet by creating a global mutual fund with a small insurance percentage on top of all affected assets would likely be enough by itself to finance the great cooling exercise we propose to the world. We can do this by implementing the combined actions mentioned in the other chapters.

The theoretical possibilities to increase precipitation through targeted revival of biological activity may well be another great investment with an amazing return on investment. While in most areas we need action rather than more scientific research, this specific area of research should be on top of the scientific communities list in conjunction with understanding the whole issue of globally interconnected atmospheric hydrology driven by biological activity. Whether it is about saving the Amazon rainforest, stabilising the Indian monsoons, fighting the droughts in the Horn of Africa or fighting the drought/flood events of Australia and California, they are all tied to the disruption of atmospheric hydrology caused by the destruction of the climate regulation capacity of once healthy ecosystems.

# Chapter 13
# Reforming Global Food Production

## Disclaimer

*We don't have the expertise to detail pathways to the transition of the global food production system towards regenerative agriculture and sustainable food production. What we do in this chapter is sketching a few important thoughts and directions that will help the reader form an overall idea of the ways and the scale at which food production and consumption patterns will need to change.*

## How Grass Seeds Started the Climate Crisis

We are living with eight billion humans now on this planet and, together with our food production and livestock, we are a dominant biomass, even affecting the way the planetary climate system operates. The relatively recent explosion of the human population can be compared to a grasshopper scourge in terms of how fast we are depleting the natural resources of our beautiful, living but finite planet. Fossil fuels allowed for industrialization of food production, while antibiotics and better hygiene increased longevity. But the story actually starts with the cultivation of grass seeds as a huge game changer in the development of our species, all of which led tangentially to an impact on climate, in particular, as we cleared forests to make way for our crops.

Humans started to cultivate grass seeds, such as wheat, rice, and barley around the world, starting at around 12,000 years ago. In the Middle East, the cultivation of wheat and barley began around 10,000 years ago, while rice cultivation in China started around 7,000 years ago and in the Americas, the cultivation of the C-4 maize species began around 5,000 years ago. This first agricultural revolution was a major factor in the transition from the nomadic hunter-gatherer lifestyles to one of settled agriculture and the establishment of permanent settlements. This had a huge effect on forests as they were cleared both for the construction of villages and walled towns and to provide land for growing these new food staples that could be stored for consumption during lean months. Simultaneously humans started to domesticate animals as well, using them for food, labour and as pets. While canine ancestors must have formed bonds with hunter-gatherers' way before this time, many more animals were domesticated once humans began living in long-term settlements. The earliest evidence of animal domestication comes from the Middle East, where sheep, goats, pigs, and cattle were first domesticated during the Neolithic period. Horses, camels, llamas, and reindeer would follow in the centuries and millennia that followed. Cats invited themselves around the grain stores that had attracted mice and rats and they have kept humans as pets ever since.

All this clearing of forests had a profound effect on the atmospheric hydrology of the areas where these settlements grew fast and formed cities. The best example is the desertification that happened after the great cities of Mesopotamia arose in what is now Iraq. The area was called the fertile crescent, but the rains diminished as the region was deforested. Indeed, Mesopotamia was once covered in thick forests of oak, tamarisk, and pistachio trees, but became more arid owing to deforestation and to increasing salinisation as irrigated water vaporised and left salts behind. Such forests and savannas once stretched from the Nile River to the Persian Gulf in the east. It is very likely that the forest cover extended to the now largely bare areas of coastal Iran, Pakistan and all the way to the Thar desert in Western India. Whereas, in Mesopotamia, the two rivers Tigris and Euphrates dominated the fertile crescent, the northern part of the Indian subcontinent was dominated by the mighty Indus and Ganges rivers and their tributaries. The settlements that formed around agriculture and animal husbandry there were developed later than in Mesopotamia but again had the same effects: deforestation and aridification of the areas. But even more importantly, the Indian monsoons that used to connect atmospheric rivers all the way from the Bay of Bengal to West-Africa and onwards to the Amazon basin, were interrupted by the felling of trees in those fertile river areas.

## A Pernicious Food, Water and Energy Problem

Food, water and energy are the unconditional foundations of life and therefore of human societies and they are intricately connected. In this age of multiple crises, the acceleration of the destabilization of the climate accompanied by fast increasing extreme weather events and an ever-increasing human population are together impacting the food and water provision for a sizeable proportion of the human population. Reforming the global food production system requires huge changes in land regeneration, sustainable water management and decoupling the production of food from the input of fossil fuels. Of all the challenges we have to get through, that facing us as to how we obtain our food, water and energy is the most pressing, especially because the lack of any one of them can derail societies and explode into famine, conflict, war and mass migration, rapidly diminishing the capacity of societies for managed change. Of all the issues facing our species, we put food security and the access of sufficient food for all at the top of our priority list.

Water is critical input for food production. Large amounts of water are used to grow food and keep livestock. At least 70% of freshwater used by humans is used in the production of food and, in some countries, this can rise to 90%. The production of meat and dairy products are particularly water-hungry.

At the same time, the global food production system is heavily dependent on fossil fuels, as they are used for various processes involved in agriculture, including transportation, production of fertilizers, and running machinery such as tractors and harvesters. The use of fossil fuels in agriculture has enabled increased productivity and efficiency in food production, but it has also led to massive land use change and soil degradation. Together with the increased emissions of greenhouse gases, the land degradation from agriculture is causing significant climate change. It has been estimated that for each calorie of food on our plates as much as 8 or 9 calories of fossil fuel energy will have been used.

Food security and access to healthy food are at the core mission of the Food and Agriculture Organization of the United Nations (FAO). This institute has been closely monitoring the impacts of climate change on global food security and concludes that climate change is already affecting food production substantially, with changes in temperature, weather and rainfall patterns already affecting crop yields, livestock productivity, and fisheries. The current trend is toward rapid increase of food insecurity, particularly in regions that are already vulnerable to food shortages and malnutrition. Food systems around the world will need to adapt quickly and profoundly to these challenges in a world with daily more mouths to feed. While adaptation, improved water management, climate change resistant species, reducing food waste and very importantly localizing food production and consumption are all necessary, the most important measures we can take is to regenerate soils, land and the small water cycles to bring back to life the full capacity of ecosystems to produce food both on land, in rivers, lakes and the seas.

## Another Green Revolution, this Time a Sustainable One

The total food production and consumption revolution that is necessary to feed billions of people sustainably, while at the same time allowing for the precious ecosystems around the world to regenerate, will require a huge and multifaceted change in the decades to come.

As said earlier, it is outside the scope of our book to describe this in detail but the changes will be profound. We need, therefore, to reduce the fossil-fuel energy and freshwater input into our food production, all of which leads to several key and necessary changes for us to achieve sustainable food production around the world, with access for all to enjoy healthy and tasty food.

## Reducing Oil in Our Food

Currently for every calorie of food on our table eight or nine calories of fossil fuels are consumed. Let alone our concerns over global warming from greenhouse gas emissions, the consumption of fossil fuels in agriculture and food production is completely unsustainable. Therefore, one of the most important changes we need to institute is the bringing together of production and consumption. This localisation of feeding, does not just mean that we should not be eating mangoes in Europe year-round flown in by aeroplanes, but also that we must stop feeding livestock in Europe and China with soybeans and corn from areas in the tropics that have been deforested to make way for the production of fodder: as in the no-so-distant past, livestock must be fed by locally produced animal feed! Prices change behaviour and a huge price on greenhouse gas emissions of at least a hundred dollars per ton of $CO_2$ would quickly facilitate this shift.

## Reducing Animals in Our Food

Which brings us to the second important key, we need to shift towards more plant-based diets. While we are not proponents of vegan diets, this shift needs to happen. Maybe meat should become a special treat as it was in the olden days. It is well known that animal protein requires much more land, water, and energy compared to plant-based foods. Therefore, shifting towards plant-based diets can help to reduce the environmental impact of food production. Around 80% of all land tied to food production around the world is used for the production of livestock and animal feed. It is clear that we need that land to restore the ecosystems. According to the FAO at last count in 2020, about 38% of the Earth's land surface was used for agriculture, including crops, pastures, and forests converted for agricultural use. This is roughly an area 5 times the size of the US or China.

## Using All the Food

Undoubtedly, we should reduce food waste since around one-third of all food produced globally for humans is wasted. But we like to look at this problem in another way. On a sustainable farm there is no food waste because food that is not used by humans will be used by other living beings, whether it is composted for biogas or simply given as feed to pigs and fish. In a fully circular world, waste production is simply input for another cycle of biological activity.

## Transition to Permaculture and Agroforestry

One of the most important ways to transition to sustainable food production, especially in the tropics, is to grow food in the form of multi-species agroforestry and forms of integrated permaculture, as part of climate-resilient landscapes. Perennial plants make up the majority of food producers in these systems and, while they do need intensive cultivation and harvesting practices, they produce a healthy variety of foods in addition to high value crops such as spices and medical plants. And in well-designed landscapes, there is room for biodiversity, indeed, agroforestry systems provide corridors connecting areas for the migration of species. In a fully mature, well-balanced agroforestry system in the tropics, the biodiversity level can be as high as sixty percent of an adjacent mature tropical rainforest!

A great proportion of these food systems are tropical, given that agroforestry and permaculture tend to be more viable than in colder regions with cold winters. Nevertheless, many perennial food plants and trees in colder climes are well-suited for cultivation, such as apple, pear, plum and cherry trees, and a variety of berry-growing plants and shrubs.

Perennial vegetables like rhubarb, asparagus, horse radish and other tubers like artichokes can also come into their own as good nutritious sources. These, together with hazelnuts, walnuts, chestnuts, as well as mushrooms and edible tree leaves, can make for all-rounded, good nutrition. Annual plants and grains will continue to be a major part of the food supply in these regions. The same goes for the tropics though. While perennial rice exists, the grains used in general are annual plants and that also goes for many vegetables and tubers. Key elements in this whole process are to return to more localised and seasonal food production, less processed foods and less animal protein in the mix. Abundant and rich servings would be kept for feasts and parties, while everyday food would be nutritious, tasty, and healthy.

As we began our chapter with a story on grass seeds, it is clear that the world cannot transition entirely away from these important food stocks but in a new green revolution these grains will be produced in much smarter ways, with much less tillage and using cover crops to keep soils healthy and hydrated. All kinds of forms of precision farming can help to reduce the use of water, harmful chemicals and protect the environment.

The revolution that is going on in designing new sustainable ways of food production is enormous and there are literally thousands of projects around the world that are experimenting with this, hugely helped by the internet that allows for the rapid exchange of new information and best practices. Hereunder we would like to describe another few examples of where the future of food might bring us.

## The Sea on Your Table

In the metamorphosis of the global food system, marine ecosystems are likely to come out as significant contributors to global food production. Some forms of aquaculture farming of fish, shellfish and seaweed already exist and would be a part of the equation. Seaweed is nutritious and a staple food in several Asian countries. What needs to be developed more is biodiverse marine food production in so called integrated multi-trophic systems (IMTA) based on a more balanced food production. Current aquaculture of salmon, for instance, relies on the use of fish feed and results in high levels of waste and pollution, including the use of large quantities of antibiotics and toxic chemicals.

It is ironic that for Norwegian salmon fish farming soybeans are used as feed, which is causing deforestation in South- America! In IMTA the combination of animal and vegetable crop mixes can increase food production without the negative by-effects and in fact improve water quality of coastal areas. Large oyster and mussel beds can have a tremendous impact on the quality of coastal seawater as they filter and remove excess nutrients, creating a cleaner and more sustainable environment for all marine life.

Japan has been a good example of integrating seafood into their eating culture, reducing their reliance on land-based agriculture. An island like the UK would not be able to feed itself with land-based sustainable food production, but once it would substantially increase sustainable aquaculture in its coastal waters, it could get much closer to food sovereignty.

## A Fly in Your Soup

While eating insects will give an itch to a lot of people, those small, rather off-putting creatures are already a staple diet in many parts of the world. In Thailand, insects such as crickets, grasshoppers, silk moth pupae are commonly eaten as snacks or as ingredients in dishes like stir-fries and soups. Fried large scorpions are even an expensive delicacy! In Mexico, *chapulines* (grasshoppers) are a popular snack, often seasoned with chili powder and lime juice, and in Africa, local and often seasonal dishes are made with insects, such as in Cameroon, where termites and caterpillars are often used in traditional dishes such as *ndole*, a stew made with bitter leaves, nuts, and insects.

The consumption of insects can help feed the global population in a future sustainable food production system. Raising insects for food requires far less resources than for instance animal farming. Insects require less land, water, and feed to produce the same amount of protein as livestock, while producing a lot less waste. In fact, the ''waste'' can quite often be recycled into fertilizer. Insects can be easily farmed or harvested in the wild and need a lot less infrastructure to do so. Insects can also be used in earlier steps in the food chain, such as in sustainable shrimp farming, using black flies as feed for the shrimps.

## Natural Fertilizers

While we described marine ecosystems and insects as two possible large solutions for making food more sustainable, less resource intensive to produce and transport, we can also look at these lifeforms as feedstuffs for livestock:

> ''Farmed insect protein such as mealworms, crickets, and black soldier flies offers a solution to the growing challenge of how to sustainably feed livestock: fast-growing and resource- efficient, these creatures rapidly produce tons of protein, without the costly and damaging inputs required to produce grain or grass for feed.'' *Insect farming byproducts are piling up. They could be fertilizer in a circular agricultural system*.

## From Disaster to Opportunity

Sargassum seaweed, as the name suggests, is associated with the Sargasso Sea which is in the Atlantic Ocean, some way off from the coast of the United States. Recently, a large seaweed blob, involving millions of tons, broke free and threatened the beaches of the Caribbean. Once it starts rotting, the seaweed gives off pungent smells and causes irritated skins and eyes. If seaweed blobs of this magnitude make a landing, it will likely have a huge impact on the multi-billion-dollar tourism industry of places like Florida, Yucatan and many of the Caribbean islands.

The likely cause of the bloom was a combination of higher seawater temperatures and run-off from additional industrial agriculture in the watershed of the Amazon River, as large areas are being deforested to make way for corn, sugar cane and soybean fields to feed the world's livestock and humans. The nutrient rich runoff of synthetic fertilizer combined with the wash-out of recently deforested soils, carrying away the natural nutrients, have created ideal circumstances for the weed to bloom in an area the size of a continent. While sargassum weed provides important habitats and serves as a food source for a variety of marine animals such as fish, sea turtles, and birds, these excessive amounts of Sargassum weed not only affect the tourist industry but are also killing marine ecosystems, as they can deplete oxygen levels in the water and disrupt these ecosystems in other known and unknown ways. One of the ways to encounter this bloom is to harvest it as fertilizer, animal feed and possibly biofuel as the sargassum is an important sink for $CO_2$ which can then be recycled into the food and energy systems.

## Ancient Sustainable Food Production, the Balinese Subak System

The Balinese Subak system stands as a testament to the ingenuity of traditional agricultural practices that prioritise sustainability, cultural preservation, and harmony with nature. This food system protects nature and biodiversity, keeps soils vital and no pesticides or chemical fertilisers need to be used. A charming example is how ducks play an important role as natural allies to rice farmers, offering pest control, weed management, fertilisation, and ecological balance. But, also fish, like carp and tilapia, are important to the whole system.

Fish coexist with other organisms such as frogs, snails, and insects, which together with the ducks create a balanced and diverse ecosystem. This biodiversity helps maintain ecological stability and resilience, making the rice paddies more robust and adaptable to environmental changes, while feeding visiting birds and resident non-venomous snakes which are tolerated as good rodent catchers.

**Figure 54:** *Subak system in Bali - Stunning view of the Tegalalang rice terrace fields during sunrise – Photo Travelwild/Shutterstock*

The Balinese Subak system is a shining example of traditional water management, sustainability, and cultural heritage that has been practised for centuries on the Indonesian island of Bali. It represents a harmonious blend of social organisation and water and land management, primarily utilised for organic rice cultivation but extending its influence to other forms of food production, including vegetables, tree fruits and other agroforestry produce such as spices.

The origins of the Subak system can be traced back over a thousand years, reflecting the deep-rooted agricultural traditions of Bali. It was established during the Majapahit Empire in the 9th century and has since evolved into a sophisticated and highly efficient model of water management. At the core of the Subak system lies a profound philosophy, called Tri Hita Karana (can be translated as three causes of happiness and prosperity), emphasising harmony in multiple dimensions: harmony among the people, between humans and nature and between humans and the divine.

The Subak system operates through a structured organisation of water management units. At the lowest level are individual farmers who collectively own and manage small sections of rice paddies. These farmers are members of a Subak, a cooperative organisation that oversees water distribution. Each Subak is responsible for managing the water from the source, typically a mountain spring, to the rice terraces.

The Subak system's success hinges on its intricate water governance mechanisms. Water temples, known as "Pura Tirta," play a central role in this system. They are responsible for blessing and distributing water to the rice fields. Water priests, who hold a sacred role, conduct rituals to ensure the continuous flow of water and the synchronisation of planting and harvesting times. The distribution of water in the Subak system is a meticulously orchestrated process. Canals, tunnels, weirs, and dams are constructed to channel water from its source to the rice terraces. Water flows slowly, ensuring optimal soil and aquifer water retention, while simultaneously preventing erosion and mitigating the risk of flash floods during heavy rainfall.

Regular meetings among Subak members are fundamental to decision-making. Here, they discuss water distribution schedules, maintenance of irrigation infrastructure, and other communal matters. Collective decision-making fosters a sense of ownership and responsibility among the community members. These cooperatives also have an elaborate list of cultural celebrations that are deeply intertwined with agricultural activities. These celebrations mark important milestones in the farming calendar, such as planting and harvesting seasons.

## Fewer Cows, and Put Them Under Trees

The amount of land used for livestock needs to be diminished and regenerated worldwide, but especially in the tropics. Turning to silvopasture is one option. Since we must diminish the footprint of fossil fuels in the food chain we must feed cattle with local fodder, not from the other side of the world. Bio-industry as a whole is a narrow-minded form of food production which must be taxed for its externalities.

To achieve long-term sustainability, it is necessary to implement sustainable fishing and aquaculture practices. This includes equitable resource access, governance improvement, and innovative technology adoption. On land fish ponds, lakes and rivers must be part of the total water cycle and watershed management and be part of the environmentally sound circularity of nutrient cycles.

Food production in the tropics should turn in more places to high value crops embedded in agroforestry taking care of soils, erosion and the water cycle. Step by step large scale pesticides and chemical fertilizers must be replaced with more regenerative systems. For reasons of soil protection and keeping the climate cool, bare grounds should be banished by law and need to be covered by cover crops at all times, which will also improve soil fertility. Crop and fruit production and consumption must become more localized and also re- seasonalized. A high price on the use of fossil fuels will make wasteful production in greenhouses unprofitable. Food production in a region must be focused on providing all aspects of a healthy and varied diet all year long.

**Forests and Wetlands**: Protect and regenerate ecosystems by engaging communities, the aim being to halt deforestation, restore landscapes, and promote sustainable practices through robust monitoring and stakeholder engagement.

**Soil and Water**: Focus on governance, water management, and regenerative farming, including reducing chemical inputs and promoting sustainable land and freshwater management.

**Food Loss and Waste**: Minimize food loss and waste through technological advancements, optimized production and distribution, and fostering circular economic practices.

**Clean Energy**: Align with IEA's Net Zero Roadmap 2023, focusing on sustainable biomass- sourcing and efficiency in agrifood systems, while managing bioenergy's impact on food and the environment.

**Inclusive Policies**: Ensure justice, education access, and social protection to achieve sustainable development goals. Focus on climate finance, risk management, and transparent trade systems for inclusive and sustainable agrifood systems.

**Data**: Improve emissions measurement, agree on common metrics, and strengthen land tenure monitoring. Facilitate inclusive access to digital tools and protect data rights for agricultural advancements.

# Part Three
# How Can We Solve the Climate Crisis Within Our Lifetime

# Chapter 14
# It Is High Time to Change the Operating System of the World

**Figure 55:** *Image of a new world arising – Rob de Laet/Dall-E*

The year 1972 saw two major reports on the state of the world with respect to concerns about the damage to the environment from the rapid post-World War 2 spread of industrialization. The first report, *Limits to Growth*, from the *Club of Rome*[1], indicated that, at the rate of the then-industrialised expansion, we would run out of essential materials, including petroleum, while destroying our health and that of ecosystems from pollution and toxic contaminants. The second report, *Blueprint for Survival*, from the editors of the *Ecologist Magazine*[2], called for a drastic change to the way we lived our lives, from material throw-away consumerism, to one of carefully nurtured conservation and the protection of what we have now come to describe as *essential ecosystems*.

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[1] https://www.donellameadows.org/wp-content/userfiles/Limits-to-Growth-digital-scan-version.pdf
[2] https://en.wikipedia.org/wiki/A_Blueprint_for_Survival

The year 1972 was also the year of the first-ever United Nations Conference on the Human Environment (UNCHE), which tried to bring to light the growing concerns that we were ruining our environment in the headlong rush to industrialise. Climate-related issues were not then the order of the day.

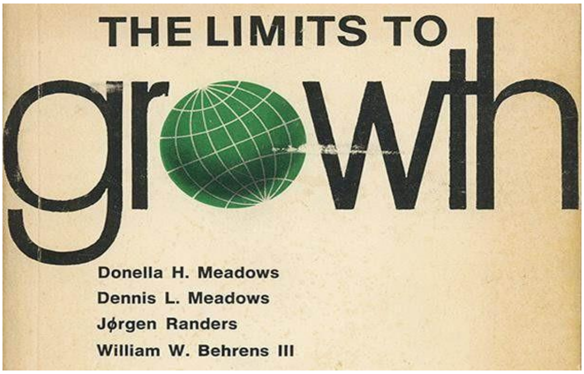


**Figure 56:** *Cover of the Game Changing 1972 Publication ''The Limits To Growth''.*

Since the environmental awakening of 1972, modern humans have slowly woken up to the realisation that the Earth, once seen as a limitless treasure trove for the taking, with its cornucopia of minerals, forests, grassland for cattle, oceans of fish, coal, oil and natural gas, could be irreversibly damaged by the growing consumerism demands of an expanding world population. Although not considered in 1972, human-caused climate change, with the chaos brought about by an ever-increasing incidence of extreme-weather events, has become the face of the widespread damage we have done to the natural world and to essential ecosystems, such as the grand forests which we had inherited before the industrial revolution took place some 200 years ago.

**Figure 57**: *Dump trucks unloading garbage over vast landfill. Smoking industrial stacks on background. Photo by Gorloff/Shutterstock*

As the adverse impacts of climate change make themselves increasingly evident, it is becoming clear that we are unlikely to achieve in time the calls for reductions in greenhouse gas emissions to net-zero, while simultaneously sustaining our economies with renewable energies and resorting to energy-costly schemes of carbon capture. To meet the aspirations of future generations, we must come to understand that the climate we endure, and from which we have benefitted, is in grand part a product of the interaction between life-support ecosystems and the Earth's surface, including its soils and oceans. In that respect, we need to recognise that the atmosphere, with its oxygen content and its greenhouse gases, is primarily a creation of life and its aeon-long evolution. For the sake of our futures, we must get away decisively from those economic practices which lead to ever more environmental destruction and degradation, while simultaneously instituting the way to restore and regenerate a healthy environment. That way, we will cool the Earth.

With technological developments and advances, especially how they pertain to global communications, we can deploy strategies that have the potential to accelerate the great turning towards a sustainable future. A large part of the global economy must quickly be redesigned to protect the planet and our societies while realising Sustainable Development Goals[3] which will include the ubiquitous management of natural resources such as to improve the quality of life for all people, including those currently at the margins of society through no fault of their own. We need a major worldwide-effort, including everyone, to regenerate the biology of the planet. In effect, the world of nature, with all its complexity and plethora of organisms, is, without exception, the fundamental source of our livelihoods.

## What is Needed for this New Operating System?

### Falling in Love with the Earth

The new operating system needs a new narrative. Capitalism, whether Private or State, has been very successful in spinning a compelling tale that when individuals act on their own self-interest within a free-market economy, they contribute to the societal well-being of all. The competition within these markets, looking for opportunities to make profits, propels businesses to innovate, enhance efficiency, and cater to consumer needs, that are themselves the result of a response to market forces. This cycle of competition and innovation then generates wealth, employment, and helps to improve living standards across society, effectively allowing wealth to 'trickle down', such as through taxes on profits.

The narrative posits that as the wealthy invest in businesses, that process leads to job creation and income generation for others, which subsequently fuels demand for various goods and services, thereby fostering further cycles of growth, spreading out over the whole of society. It is obvious that, while this system has indeed created enormous wealth for a large minority of the global population, particularly in the last century in Europe and the US and more recently

[3] https://sdgs.un.org/goals

in Asia, it has done so in an unsustainable way and at the expense of the future. The current system relies on the exploitation of natural resources, thus contributing to the destruction of the biosphere and, by the industrialization of agriculture, cordons-off land, thus disenfranchising millions upon millions of people who traditionally had worked and cared-for the land which had been their inheritance from their forebears. Many of those same people have had no option but to migrate to cities, where they live in slums and work for a pittance as small cogs in the global system. The result of such 'declared' progress is a terrible quality of life for hundreds of millions of people.

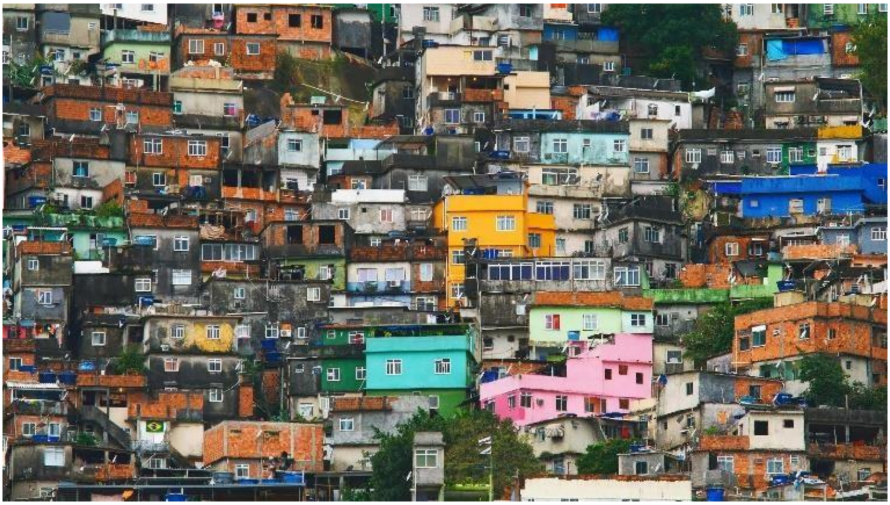

**Figure 58:** *Arial view of Rocinha – the largest favela in Rio de Janeiro. Photo J-UK/Shutterstock*

In effect, the short-term focus of the free-market economy does not take into consideration the notion of perpetuity and that we must take care of our planet such that the profits of today derived from natural capital are not at the expense of the future. In generating their wealth, today's enterprises take little to no account of the externalities associated with natural capital, with the result that they do not pay for the environmental and social degradations which they incur. And, by the same token, positive externalities, like the responsible stewardship of

Indigenous peoples of their lands and which leads to environmental improvement, are not rewarded.

We have to leave this old narrative behind and embrace a new one. We can find an uplifting example of this brave new world in the book "A More Beautiful World Our Hearts Know is Possible," by the American writer Charles Eisenstein[4]. In the book he explores the stories that have shaped our world and particularly the narrative of separation that underpins much of modern civilization. Eisenstein encourages us to shift towards a new Story of Interbeing, one that recognizes our deep interconnections with each other and the natural world. This new narrative opens pathways to empathy, understanding, and cooperation, leading us towards a more beautiful, just, and sustainable world.

Another sage-like person, Joanna Macy, who is now in her nineties, and is a renowned environmental activist, scholar, and author, centres her thinking on the interconnectedness of all life. She stresses the need for humans to take up their responsibility to protect the Earth. She has developed a framework for personal and social change, known as "The Work That Reconnects,"[5] which combines spiritual insights with systems theory and Buddhist principles. Of particular beauty about our role in these dangerous times is her telling an ancient Tibetan legend of the coming of the kingdom of Shambhala which is told to her by a shaman. The story goes like this:

> "There comes a time when all life on Earth is in danger. Barbarian powers have arisen. Although they waste their wealth in preparations to annihilate each other, they have much in common: weapons of unfathomable devastation and technologies that lay waste the world. It is now, when the future

[4] https://charleseisenstein.org/books/the-more-beautiful-world-our-hearts-know-is-possible/

[5] https://www.joannamacy.net/work

of all beings hangs by the frailest of threads, that the kingdom of Shambhala emerges.

‘’You cannot go there, for it is not a place. It exists in the hearts and minds of the Shambhala warriors. But you cannot recognize a Shambhala warrior by sight, for there is no uniform or insignia, there are no banners. And there are no barricades from which to threaten the enemy, for the Shambhala warriors have no land of their own. Always they move on the terrain of the barbarians themselves.

"Now comes the time when great courage is required of the Shambhala warriors, moral and physical courage. For they must go into the very heart of the barbarian power and dismantle the weapons. To remove these weapons, in every sense of the word, they must go into the corridors of power where the decisions are made.

"The Shambhala warriors know they can do this because the weapons are mind-made. This is very important to remember, Joanna. These weapons are made by the human mind. So, they can be unmade by the human mind! The Shambhala warriors know that the dangers that threaten life on Earth do not come from evil deities or extraterrestrial powers. They arise from our own choices and relationships. So, now, the Shambhala warriors must go into training.

"How do they train?" Joanna asked.

"They train in the use of two weapons. The weapons are compassion and insight. Both are necessary. We need this first one," he said, lifting his right hand, "because it provides us with the fuel, it moves us out to act on behalf of other beings. But by itself compassion can burn us out. So, we need the second as well, which is insight into the radical interdependence of all phenomena, connecting all things. It lets us see that the battle is not between good people and bad people, for the line between good and evil runs through every human heart. We realise that we are interconnected, as in a web, and that each act with pure motivation affects the entire web, bringing consequences we cannot measure or even see.

"But insight alone," he said, "can seem too cool to keep us going. So, we need as well the heat of compassion, our openness to the world's pain. Both weapons or tools together are necessary to the Shambhala warrior."

**Figure 59:** *Joanna Macy. Photo by Adam Loften.*

Joanna explains that in these mythical times the answer lies in our courage to face the danger and subtle intelligence needed to see how all the crises we face are interconnected. She emphasises that we can make the jump in consciousness by embracing our emotional responses to global issues and thereby can shift from a self-centred perspective to an ecological worldview that recognizes our interconnectedness. She encourages us to view ourselves as part of the living Earth, providing a roadmap for our personal and collective transformation necessary to navigate the great global crises of our times.[6]

[6] https://www.youtube.com/watch?v=z6TM8g2YNDo The Shambala Warrior Prophecy with Joanna Macy on YouTube.

Maybe the most radical of all is the author, Daniel Pinchbeck. In his book "2012: The Return of Quetzalcoatl"[7], published in 2006, he draws upon shamanic experiences and ancient prophecies that humanity is on the precipice of a radical transformation in consciousness. The return of Quetzalcoatl, the feathered serpent deity of the ancient Mesoamericans, symbolises this shift – a shift away from our ego-driven, technocratic civilization towards a more spiritual, interconnected awareness. In his book of 2017, "How Soon is Now," Daniel delivers a provocative exploration of the ecological crisis as a rite of passage or initiation for humanity. He presents the current environmental emergency not just as a problem to be solved but as a necessary evolutionary push towards a fundamental shift in human consciousness, a metamorphosis. Drawing on extensive research into other cultures and economic systems, Pinchbeck outlines a comprehensive redesign of our current systems. He calls for a shift from a society rooted in competition and individualism to one based on cooperation and interconnection, with an underlying sense of urgency. Daniel offers a radical vision of a future that could avert ecological collapse. Throughout the book, Pinchbeck underscores the idea that the answers to our crisis lie not just in technology or policy changes, but also in a spiritual and psychological transformation, in which we recognize and embrace our integral role within the Earth's ecosystem.

This book embraces and tries to integrate all these stories into a challenge to the new generation to take action NOW at the speed and scale needed to avert global collapse and combine this with redesigning their future and new structures to become guardians of the Earth. When the young rise up, elevate their creativity and realise their agency they can reinvent our role as a keystone species in the evolution of life on Earth. Because we are running out of time to avert the worst-case scenarios, the new generation will need to 'fly the plane while building it'. The much-needed transformation will involve cooperation on a scale magnitudes larger than anything our species has ever undertaken. The

[7] ISBN 10: 1585425923 / ISBN 13: 9781585425921, Published by Penguin, 2007

new operating system is not just based on a new story but also on the calibration of a new set of values. Never before in the life of our species, since our ancestors left the tropical forest edges of Africa, has our future been so endangered, hanging in the balance by our own ignorance and overzealous behaviour.

## Values and Principles of the Great Regeneration Movement

The new and yet ancient paradigm, of our being wholly dependent on the well-being of the natural world, necessitates an understanding of the biosphere as a vast interconnected web of life, which has come into being by means of its evolutionary and genetic connections to the past. In this world view all living organisms are intricately linked and mutually dependent. This perspective is grounded in a holistic and eco-centric understanding of the world, contrasting sharply with the human-centred and Cartesian rationalist worldview that has been prevalent in Western thought for centuries and which must now be radically modified.

Later, we will present an economic model to attribute values to nature as an aid to the transition, but first we must emphasise that the dignity, beauty and functionality of nature is an intrinsic value and, therefore, putting a proper price on its healthy functioning is a vital step in leading us from the imploding paradigm, that nature is free to be exploited, to the new one in which its value is properly realised as a stabilising force. In the new world that we must create, we will have to provide legal status and protection for the natural world, its rivers, forests, oceans, marshlands, grasslands and for the creatures which live within them. The bio-cultural diversity of the world is of critical importance for stabilising flows of energy and minerals within the biosphere which stretches from the Earth's surface to the upper atmosphere. Hence, the interaction between species ensures that the atmosphere has just the right combination of gases for our own species to flourish. Fertile soils, with adequate watering, are also a consequence of the metabolic activities of a host of different organisms, from single-celled amoebae, to fungal mycorrhizae, earthworms and vegetation. We need the full panoply of such organisms for generating the material abundance on which we rely.

In the new, regenerated world our basic needs would be provided for by a thriving biosphere and a caring society. The challenge to regain such a world is immense, but doable. Yes, we humans have destroyed half of global living biomass and only when we have reversed that situation will the abundance, that was once the property of fertile soils and lands, have a chance of returning. We believe that we humans will come to know the advantages and benefits from embracing more down-to-Earth, sustainable lifestyles in a material, spiritual and cultural sense. The celebration of the gift of life will play a pivotal role in our new societies and the ''Do No Harm'' principle will be at the heart of decision-making as we take into account the interconnectedness both in time and space of all life past, present and yet to be born. From this renaissance, based on a complete shift of perception of the meaning and role we have in the great journey of life on Earth, we will need to achieve a practical implementation of the metamorphosis. If enough of us embrace this new story with our hearts, minds and hands, we are on our way to create this new future of simple abundance and care as part of a living planet looking for new challenges into the cosmos and other yet unknown dimensions of the future.

## The Rights of the Planet and the Establishment of the Global Commons

The Earth belongs to itself and we humans belong to her. This is our only home and she, as a biosphere of all living organisms and those yet to come is in that sense alive. She, utilising the energy of the Sun, has given us life and, for that, is our common mother. We emerge from her and go back to her at the end of our lives. Let us keep the Earth in our hearts with all we do and declare her to be sacred.

The Earth needs careful, loving stewardship by generation after generation of her children to keep her in a great shape for the benefit of countless generations to come so that they can add their adventures, discoveries and stories to the collective story of life's evolution. If we get through the current crisis, new avenues will open up and our restless species will no doubt make increasingly better attempts to discover the infinite universe. But first we need to get our own house in order, restore her lost vibrancy and educate newcomers about the abundance of the Earth and how it depends on our common behaviour.

In 2017, New Zealand passed groundbreaking legislation recognizing the Whanganui River, a river of great significance to the indigenous Māori people, as a legal person[8]. It was the result of a long legal battle and reflects the Māori worldview that sees themselves as deeply connected to the land and waterways. The river can now defend itself and is represented through its guardians, who are appointed by the government and the Māori community. If the thought at first sounds strange, we need to remember that legal personhood has been established for institutions and companies for many centuries, so why not apply this for crucial features of our planet?

Therefore, let us set up the Earth as a legal person, and bestow upon her the rights and ownership of all those things that matter to her well-being and with that the well-being of current and future generations. This ownership is what we call the Global Commons, represented by a council of guardians appointed by the global community. These guardians act in the name of the Earth, are responsible for protecting its status and health and well- being and can represent her in legal matters.

We can bypass the cumbersome negotiations needed to get anything done in the United Nations and can form a digital decision-making body in the Digital Gaia where a quorum of people from around the world would appoint these guardians.

[8] https://www.parliament.nz/en/get-involved/features/innovative-bill-protects-whanganui-river-with-legal-personhood/

**Figure 60:** *Māori warriors with tattoos, celebrating Waitangi Day – Photo Umomos/Shutterstock*

## What belongs to the Global Commons?

It would be most logical to make the Earth as a whole the sovereign property of the Legal Earth and all ownership of land subordinate to the Legal Earth, setting clear rules of stewardship for all land, water and natural resources. This means that air, water, the soils, all species and so on belong to the Earth and can only be used and harvested responsibly, with care and respect for their well-being, leaving the ecosystems intact upon which their permanent well-being depends, which also ties in with the rights of future generations to a decent quality of life.

While not operating from the Living Earth perspective, the ''Safe and Just Earth Boundaries'' article by Johan Rockstrom and others[9], sketches a good way to limit the use of the planet's resources so that they are used sustainably. It states that our planet's health and human well-

[9] https://www.nature.com/articles/s41586-023-06083-8

being are tightly connected. Currently, too few of us recognize this link and, for that reason, we need a framework to operate in so that we take the right decisions with respect to the long-term viability and habitability of the Earth.

The establishment of the legal personhood of the Earth's attributes, such as that of the Whanganui River, need to happen everywhere. By such means, people everywhere should be able to declare their lands, rivers, watersheds, mountains, forests, seas as legal persons and form councils of stewards that guard the boundaries of human activity so that they do not degrade the area.

## The Establishment of the Ecocide Law

The counterpart of the Rights of the Earth is the establishment of the ecocide law[10], a movement started by Polly Higgins and Jojo Mehta and now taking shape. Ecocide needs to become part of the Rome Statute of the International Criminal Court[11] as the fifth international crime. The Rome Statute established four core international crimes: genocide, crimes against humanity, war crimes, and the crime of aggression. Ecocide is described as the unlawful or wanton acts committed with knowledge that there is a substantial likelihood of severe and widespread or long-term damage to the environment being caused by those acts.

[10] https://ecocidelaw.com/

[11] https://en.wikipedia.org/wiki/Rome_Statute#

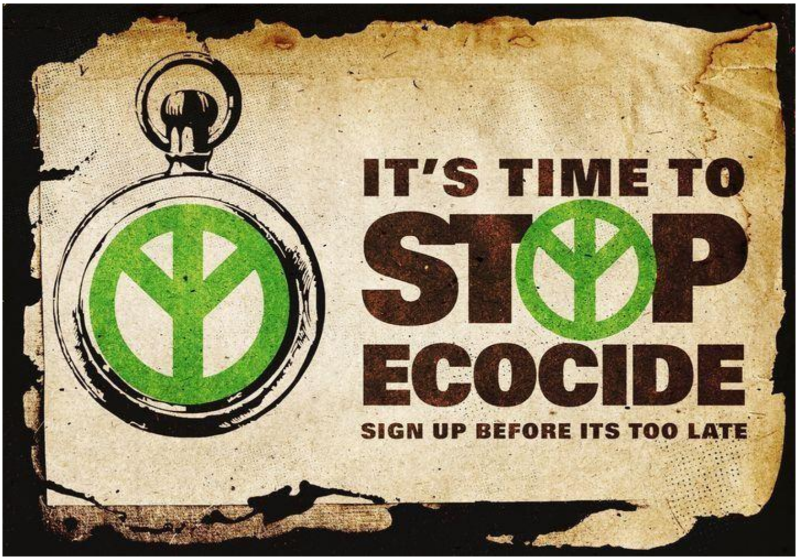


**Figure 61:** *Stop Ecocide movement – design courtesy Squiff Creative Media*

## Financing Global Regeneration

As we stand now, our house is on fire and we have limited time to turn things around before we are no longer capable of doing so. A first step must be the financing of planetary regeneration, which is both a moral imperative and a crucial strategic economic move in our combined efforts to save the future. Indeed, we need to develop innovative governance structures, a new financial system and financial instruments that can support such efforts, thereby creating an undeniable business-case for environmental restoration.

Just as the Marshall Plan was designed to rebuild economies after World War II, a similar financial strategy must be implemented globally to restore our damaged ecosystems. This, in turn, will help stabilise the climate, regenerate degraded land and support the emergence of a circular economy. For such an economy to come universally into being will require considerable attitudinal changes to make it happen. For instance, it redefines what property is and what are the boundaries within which individuals, communities and larger organisations can manoeuvre to enhance their self-interest, while being aligned to the interests of the local and global commons and the rights of nature.

The Earth is slowly being understood by modern humans as a place that requires careful stewardship, leaving its abundance intact and only taking what can be harvested while maintaining the processes that ensure sustainability, such as care for soils and maintaining its fertility. Contemporary societies, across the world, have become destructive and wasteful in the careless way they deal with the riches of our extraordinary planet. Such callous, materialistic treatment of planetary resources has not been the way of most Indigenous peoples. Although they comprise less than 5% of the world population, Indigenous peoples protect 80 per cent of the Earth's biodiversity in the forests, deserts, grasslands, and marine environments in which they have lived for centuries. Moreover, the wealth of biodiversity to be found in Indigenous areas is actually at least as high as in protected areas like national parks and conservation units, therefore indicating that their hunting and foraging activities do not reduce biodiversity and may in some instances actually enhance it. Many Indigenous cultures see themselves as interconnected with nature, viewing forests, rivers, the land and the whole Earth as sacred, conscious and alive. They practise sustainability, respect the environment, and value and teach traditional ecological knowledge, such that they are 'ecologists by culture'. They emphasise harmony with nature, storytelling, and communal values.

In contrast, modern humans have built their economies on the notion that resources are there for the taking, with minimal concern for the devastation left behind in their extraction and use. In the early 17th century, Francis Bacon heralded the idea of science being used as a means to improve the state of mankind. Nature for him was chaotic and, like a harlot, needed to be brought to order if mankind were to progress and improve the quality of life, as it then was.[12] Bacon's view of Nature as unkempt and disordered is wholly at odds with that held traditionally by indigenous communities in the Amazon Basin who, in

[12] Francis Bacon, Novum Organum. Published in 1620

sharp contrast, consider the natural world to be inherently and dynamically ordered as compared to the chaos prevalent in human affairs. In effect, the idea that scientific and technological progress is taking us to some materialistic utopia has brought about a pathological disconnection from nature.

In that respect, the current climate mess we are in is only a symptom of the much larger problem associated with the destruction of much of the web of life which, by means of feedbacks, both negative and positive, managed the Earth's planetary physiology, with its breathing-in and -out of the gases which make up our atmosphere.

In the 1970s, the historian Siegfried Giedion captured well the real spirit of progress. "The one-way street of logic has landed us to the slum of materialism," he observed with bitter irony.[13]

## How did the Current System Evolve?

With the end of the last Ice Age, some tribes in the dryer areas of the Eurasian continent, discovered fertile lands and settled, tending to the earth and turning more and more to agriculture. It might well have been that their nomadic or semi-nomadic life was no longer viable, caused by the dwindling number of wild animals. Nomads are known to have already enriched their natural surroundings with edible plants they could go back to later, but it was especially the grass seeds that turned out to be abundant and reliable food sources and maybe more importantly, storable, leaving a surplus and more time free from the search for food. It also started the necessity to protect the food-storage granaries, which meant residing in one place, while fending off marauding nomads. The more stable food supply made foraging by all less and less necessary, while the surplus harvested allowed for a growing population. This settled life also introduced the division of labour and the emergence of property rights and social hierarchy.

[13] Siegfried Giedion's book Mechanization Takes Command: A Contribution to Anonymous History, published in 1948.

Once agriculture got underway, settlements became larger and the size of social groups surpassed the so called ‘’Dunbar number’’[14], with the consequence that governance became stratified and decision-making was carried out by an elite group, supposedly representing the community. The Dunbar number is described as the maximum number of people with whom someone can maintain stable social relationships, with everyone knowing each other directly. The number is quite often put at around 150 people. When communities surpass this number, more formal rules are established and institutions are created for decision- making, supposedly with the best interests of the population at heart. In a tribal group, the chief or the shaman quite often has this role, but as populations grow, those decisions may be made by someone who is not intimately acquainted with the persons whose interests are being determined. In effect, the institutions and those who form it gain power and with that power can come dictatorship and the hunger for more power. To prevent such accretion of power, laws, rules and constitutions need to be created, with a body of experts to oversee them and ensure that they are not contravened. Such is the modern society.

Surpassing the Dunbar number also introduced what is known as the Tragedy of the Commons[15], where individual action can collectively lead to resource depletion and environmental degradation, to the point at which we have now arrived, with our degraded, abused planet showing its stress by foisting on us extreme climate-related events, with all the ensuing tragedy. Resource-grabbing has been the name of the game for millennia and with it, the creation of empires and colonisation. The issue of each out for him- or herself plays a continuous role in the inability of governments to work together on regulatory mechanisms for preventing the further degradation of the Earth.

[14] https://en.wikipedia.org/wiki/Dunbar%27s_number
[15] https://en.wikipedia.org/wiki/Tragedy_of_the_commons

## Creating a New Asset Class to Underpin Regeneration

Humans have always attributed value to items, such as gold and precious stones. They were definitely chosen for their beauty, durability and scarcity, but in the end the real value is decided by an implicit social contract between people: something is valuable because it is deemed valuable, rather than having a necessary value because it is a fruit tree, food, drinking water or wine or a rare earth needed to make a computer chip work.

In this context, a new asset class is proposed: productive, biodiverse, climate-resilient landscapes that sustainably produce food and other products, such as clean water, beauty and relaxation. The concept here is to treat land not simply as a commodity to be exploited but as an asset whose long-term value depends on its overall health and productivity. This means that the financial value of such landscapes would be measured not just in terms of their immediate yield, but also in terms of their biodiversity, carbon sequestration potential, water retention capacity, soil health, and their contribution to the economies, health and well-being of local communities and last but not least, its beauty.

We need to recognise the importance of these biodiverse, climate-resilient landscapes to secure the future, while showing that investment in them generates sufficient returns not just in a monetary sense, through the production of foods, for instance, but also because they generate ecosystem services such as clean air and water and biodiversity. These payments for ecoservices, such as carbon credits on top of the other benefits, makes investment in land regeneration attractive for investment. But in order to do that, more information needs to be organised and quantified for investors to understand risks and returns. Larger investors such as sovereign funds or pension funds typically invest in diversified portfolios and regenerative projects should not be any different, ensuring that the risk is spread and the portfolio appealing to a wide array of investors. They are also bound through their bylaws to only invest in investment-grade investments as set by the internation rating agencies.[16]

A crucial aspect is the standardisation and quantification of the impact of these investments. We must develop new metrics that accurately gauge ecosystem health, biodiversity, carbon sequestration, water retention, soil health, and socioeconomic benefits. Clear and reliable data enhances investor confidence and adds credibility to the asset class. Simultaneously, work needs to be done on creating regulatory standards and on gaining market recognition.

An increasing number of companies and investors are putting in place environmental, social, and governance (ESG) criteria to assess their sustainability efforts and to quantify their responses to climate change. These corporations often align their missions with thematic areas that work well for their stakeholders, such as water, energy, biodiversity, carbon, or broader climate-focused targets, accelerated by new regulation such as that which the EU is rolling out with its corporate sustainability reporting directive (CSRD)[17], the aim being to force 50,000 listed companies to make environmental, social and governance (ESG) disclosures in annual reports for 2024 onwards.

## Unlocking a Wave of Investment in Regeneration

And here we get to maybe the most important hurdle of unlocking large scale global investment in the regeneration of ecosystems and the transition to regenerative food production and sustainable economic activities in general. It is the crucial but cumbersome work of setting up the right system of taxonomy[18] to unlock the necessary large-scale investment. If done correctly, regenerating the planet everywhere could become the largest investment boon in the history of humanity, way greater than the energy transition and the decarbonization of the global

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[16] https://www.investopedia.com/ask/answers/what-does-investment-grade-mean/
[17] https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en
[18] https://en.wikipedia.org/wiki/Taxonomy

economy. But the market to price, compare, exchange and invest in ecological benefits right now is chaotic and in part a wild west of all kinds and qualities of projects.

Why is taxonomy important to launch a global market to regenerate the planet? Taxonomy is a classification system used to categorise and organise elements of economic activity for the purposes of reporting, analysis and comparison, making their investment manageable including the possibilities for risk assessment and return on investment. The EU Sustainable Finance Taxonomy, for instance, classifies economic activities based on their environmental sustainability. This helps investors and companies make decisions aligned with climate goals. Transparency, standardisation, and consensus are critical for creating an investable market for regeneration. The first step towards this is agreeing upon a common language, shared definitions, and protocols for ecological benefits. This level of standardisation is crucial because it allows both project owners and purchasers to understand and agree upon the qualitative and quantitative data used to assert ecological benefit claims and paves the way for a huge globally interconnected platform for the investment in regeneration of the planet and the transition to regenerative food production, circular production of goods and so on.

Accelerating this wave of institutional investment unlocking trillions of dollars over the next decades requires the emergence of a transactional marketplace that places a tangible value on ecological benefits. This involves building a platform that verifies positive ecological and social impacts, which can dramatically boost corporate sustainability efforts.

## The Creation of an Ecological Benefits Framework

One of the latest developments is that of the creation of an Ecological benefits Framework (EBF) that can help in aligning the taxonomy and valuation of ecoservices across the board. Such an accounting system recorded with or without blockchain technology can make the monitoring, reporting and verification transparent, comparable across markets and make automated price discovery on digital markets possible. This EBF can be designed to identify, track, and report a range of ecological benefit claims including but not limited to carbon. This would include benefits to air, water, soil, biodiversity, and equity, creating an exchange for market transactions.

Central to the implementation of this marketplace platform will be the widespread adoption of a machine-readable, universally-standardised visual language. This language will effectively communicate the full spectrum of ecological services and benefits associated with each project. The EBF can underpin the creation of a marketplace where ecological benefits can be traded. This would give these benefits a tangible economic value, incentivising companies to produce more of them. It could function similarly to existing carbon markets but would be broader in scope, including benefits to air, water, soil, and biodiversity. The EBF would be structured to reward companies that act as effective environmental stewards. This could take the form of financial incentives, tax breaks, or preferential access to resources or markets. Such rewards can encourage more companies to invest in regenerative practices, leading to a multiplier effect in the effort to regenerate the planet and have a positive effect on their market value.


**Figure 62:** *Digital Representation Measured Natural Assets and Ecoservices – Courtesy Ecological Benefit Framework Group. For instance, On mobile devices, purchasers—or in the case of public companies, shareholders—can now have a "baseball card" like dashboard, with the "front of the card" consisting of interactive story elements that offer a qualitative nuanced explanation of each benefit, with the "back of the card" offering a quantitative valuation of the specific ecological benefits associated with the project.*

The global financial market is a vast network where buyers and sellers trade financial securities, commodities, and other fungible items at prices determined by supply and demand. It is split into several segments, including the stock market, bond market, commodities market and foreign-exchange market. The total market capitalisation of all global stock and bond markets are over 200 trillion USD dollars, more than twice the global GDP. Regenerating the planet will need to make up a substantial portion of these markets in order to be effective in time.

Increasingly climate-related financial disclosures can aid investors in channelling resources towards more sustainable businesses. Implementing carbon pricing mechanisms can offer an economic incentive for companies to reduce their emissions. Technological innovations, particularly in financial technology, can create more efficient and accessible pathways to sustainability. But the real breakthrough still needs to happen with institutional investors who must come to realise that not only must they invest in regenerative projects to protect their total asset base, but also realise it as a real opportunity to create financial return on investment, combined with the long-term protection of the habitability of the planet as a whole.

## What does a System Look Like that would Regenerate the Earth?

### The Elinor Ostrom Design Principles

It was Elinor Ostrom, the 2009 Nobel laureate in Economic Sciences, who showed that the Tragedy of the Commons can be avoided in her book ''*Governing the Commons: The Evolution of Institutions for Collective Action*'', published in 1990. She showed that these conflicts are often avoided in the way traditional and Indigenous communities organise their limited resources together, such as equal shares of water in a village well, or how many tapirs a community could hunt at any one time, or when certain fish could be caught in a river. Ostrom identified eight "design principles" of stable local common pool resource management, which she drew up after studying many traditional and Indigenous communities:

(1) Clearly defined boundaries. The identity of the group and the boundaries of the shared resource are clearly delineated.
(2) Proportional equivalence between benefits and costs. Members of the group must negotiate a system that rewards members for their contributions. High status or other disproportionate benefits must be earned. Unfair inequality poisons collective efforts.
(3) Collective-choice arrangements. Group members must be able to create at least some of their own rules and make their own decisions by consensus. People dislike being told what to do but will work hard for group goals that they have agreed upon.
(4) Monitoring. Managing a Commons is inherently vulnerable to free-riding and active exploitation. Unless such undermining strategies are detected by norm-abiding members of the group, the Tragedy of the Commons will occur.

(5) Graduated sanctions. Transgressions need not require heavy-handed punishment, at least initially. Often gossip or a gentle reminder is sufficient, but more severe forms of punishment must also be waiting in the wings for use when necessary.
(6) Conflict resolution mechanisms. It must be possible to resolve conflicts quickly and in ways that are perceived as fair by members of the group.
(7) Minimal recognition of rights to organise. Groups must have the authority to conduct their own affairs. Externally imposed rules are unlikely to be adapted to local circumstances and violate principle 3.
(8) For groups that are part of larger social systems, there must be appropriate coordination among relevant groups.


**Figure 63:** *Ostrom's principles are nicely digitised in the form of smart contracts that echo these Indigenous forms of organisation. Furthermore, the eight principles shape the design rules of smart contracts, which David Dao, in his 2018 paper, calls Ostrom Contracts. In particular, distributed governance is woven into the contract's structure. Source: David Dao, 2018 Decentralized Sustainability*[19]

It may seem that we have drifted a long way from exploring ways to redesign finance to regenerate the planetary biosphere. Nevertheless, this exploration on how we must organise ourselves in a way that we can move to a *sustainable stewardship of the Earth* in the same way it is

[19] https://medium.com/gainforest/decentralized-sustainability-9a53223d3001

natural for parents to take care of their kids. We must protect the sacred vitality of nature upon which our survival and well-being depends. It is crucial to define how we design a financial system that preserves, protects, supports and improves the state of the lands we live on and the oceans on which we depend. The underlying principles and function of indigenous land management systems show that it is possible to steward the biological abundance of their lands, their soils, water, air, biodiversity, ecology and that this is done with sufficient equity, based on the fundamental principles of reciprocity and exchange. I take something from you and I give you back something you need from me. Indigenous dealings with the natural world are founded on the same principles. As the environmental biologist, Barry Commoner said many years ago, "there's no such thing as a free lunch!".

A new financial system that is able to promote economic prosperity and financial stability based on protecting the Earth's abundance instead of plundering it, needs to take the above considerations and options into account to be effective. And we need to act now, as we are running out of time to avert the collapse of our consumer societies and civilizations from climate-related issues.

But maybe the most revealing realisation is that, ''Smart contracts allow us to execute computer functions while digitally sending money at the same time. This is powerful as it means that we can implement and possibly install economic systems anywhere and everywhere, just like a computer program.''

## Think Globally, Act Locally, the Basis for Regenerative Action

Bottom-up governance of the commons, must operate from certain general principles such that they are effective, equitable and for the protection of the biosphere. Fundamentally, those principles need to account for the long-term health and resilience of ecosystems and communities. Consideration must be given to the impact of decisions taken now and how they might impact in the future. A model for that comes from indigenous North American communities who looked to the consequences of their actions for seven generations to come, or some 200 years hence. The above principles and considerations are meant to provide the context for designing bottom-up governance with the capacity to navigate the complexities of managing the local commons in a globally interconnected world.

## The Digital Gaia, an Architecture for Global Regeneration

The way we have degraded the Earth makes it extremely difficult to reverse the damage in the time and scale necessary. For recovery of degraded ecosystems, we need the integrated actions of literally billions of people, regenerating the Earth in millions of places by millions of organisations, communities, companies and institutions. The enormous power of modern computing makes this task feasible, by means of instant access to information through worldwide communication, and allows all to follow and develop suitable organisational structures, to design projects based on the experience of others and then to execute them. Meanwhile, the digital financing of all the anticipated community-based regenerative projects would not be possible without the latest developments in internet access, quantum computing and accelerated data-feedback that AI can organize for us. This combined with the extraordinary scope of search engines and in the widespread communication generated through social media, makes it possible to make the restoration of the planetary biosphere a real possibility.

## How DAOs are Shaping a New Era of Global Collaboration

Long before the digital breakthroughs, people had already organised themselves in forms of cooperation that were not owned by a few people but instead had distributed ownership and decision-making. But the revolution around blockchain technology or other peer-to-peer information architecture, has made these forms of organisations much more agile and scalable and we should soon be able to apply them to almost all processes that we need to guide the transition from the exploitative economy to a sustainable and equitable one.

When it comes to building global voluntary-participation distributed techno-social network to regenerate the biology of the planet and simultaneously strive for social cohesion and a more equitable in our societies, we have one existing example that few are aware of. It is the early development of the Internet and its governance[20], which featured four specially important features:

Decentralization: The Internet's success can be attributed to its decentralized nature, where each constituent network sets and enforces its own policies.

Open Standards and Interoperability: The use of open standards has been crucial in ensuring interoperability across the different networks that make up the Internet.

Multi-stakeholder Approach: The governance of the Internet involves a multi-stakeholder network of interconnected autonomous groups from civil society, the private sector, governments, the academic and research communities, and national and international organizations.

Voluntary Adoption: The technical specifications described by so called RFCs (Request for Comments) are voluntarily implemented and adopted by software developers, hardware manufacturers, and network operators around the world.

A Decentralised Autonomous Organization (DAO) simplifies decentralised ownership and decision-making through the use of blockchain or peer-to-peer technology and smart contracts, which are self-executing contracts with the terms of the agreement directly written into code. DAOs operate on the principles of transparency, democracy, and open participation. Members of a DAO typically have voting rights proportional to the amount of the DAO's tokens they hold. They can

[20] https://en.wikipedia.org/wiki/Internet_governance

propose and vote on decisions such as how to allocate resources, whether to undertake certain projects, and other matters of governance. Since these decisions are governed by smart contracts, they can be executed without the need for a centralised authority or intermediary, reducing the potential for corruption or bias. Anyone who owns tokens in a DAO is a part owner of that organisation. These tokens can often be bought, sold, or earned, enabling a fluid and open form of ownership. All rules in the DAO are transparent and accessible to everyone in the network. It's impossible to change the rules without the agreement of token holders, making the organisation fair and more resilient to amassing unnecessary wealth, control and power.

Because DAOs are based on blockchain or distributed peer-to-peer information architecture, they can operate at any scale, from locally to globally as long as the internet is running, allowing people from around the world to participate, regardless of geographical location. This opens up opportunities for a diversity of voices to be heard. It also breaks the monopoly of large corporations or governments as the decentralised web, often referred to as Web 3.0, aims to make internet interactions more peer-to-peer and less dependent on central authorities. This includes the capacity of decentralised data storage and sharing. The key is that these networks are decentralised, autonomous, intelligent, and user-empowering, maybe not that different from the way our brains operate. What still is needed is a decentralised ownership of the data transport over the backbones, internet service providers and the operation of data centres to make the power of the internet really autonomous and not controlled by powerful entities like large corporations or centralised governments.

The processes that make up life are a sheer infinite number of microscopic interactions between trillions of cells and other elements of a body. Yet their interaction, metabolism and neural connections together form a conscious body such as yours or mine. The global internet infrastructure and the human nervous system can both be viewed as extensive, intricate networks that relay and process information, with most decisions not made at the top level of the human conscious mind as it would be too complex to organise all these countless activities from a central control room. This is already mostly the case in the digital global networks which resemble the neural system of a body. It is good to use the model of the human body to further this model of development. Many processes in the human body happen autonomously, not directly commanded by the centralised consciousness. This is akin to servers in the internet processing data independently, without a central authority. The so-called peer-to-peer architecture that makes such independence possible will become a necessary condition for the world community to work together.

## Re-imagining Money and the Future of Finance

Decentralised Finance, more commonly referred to as DeFi, is a comprehensive term that encapsulates a variety of financial applications and instruments that are built upon blockchain technologies. This opens up a whole world of self-governed currencies and makes the regeneration of the future independent from traditional financial parties such as governments, insurance companies, banks, or brokers. Instead, such financial applications operate using smart contracts, which are self-executing contracts. These contracts have the terms of an agreement directly inscribed into their code, ensuring transparency and immutability. Undoubtedly, such innovative processes militate against the powers of existing institutions, which will not easily give away their monopolies. But more and more people inside those institutions understand that it will be impossible to avert collapse of complex modern societies and hence their own institutions if we do not radically alter the way we organise our economy with respect to nature and the planet, as well as with respect to the rights of other people and indeed species.

## How Much is Needed?

The total amount of investment in regeneration is in the trillions. Research by the G20 has shown that on average the regeneration of degraded land in the Global South to make it more productive with sustainable food production is somewhere between 2,000 and 3,000 USD per hectare[21] and we would need to invest in regeneration of land and ecosystems at a scale of at least 280 million hectares in the next ten years (2,8 million square kilometres) to stop the planet from heating up further and mitigate extreme weather event.[22] If the world will pay for carbon sequestration at a rate of around 50 USD per ton and pay for additional services as well, these finances would be sufficient by themselves to pay for the transition.

The way this finance would be unlocked is very project specific and can be in many forms. The technically easiest way to fund this planetary restoration project is to introduce a new version of the so-called ROBIN HOOD TAX[23], a 0,1% fee on all financial transactions happening globally. The money would go into large national and global climate repair funds focusing on reviving the biology of the planet. They would issue Green Bonds for projects at the right scale or invest in Natural Capital and Conservation Funds (NC&CFs), which creating tangible, tradeable assets for investors to contribute to environmental conservation while earning a return on their investment and a great chance to appreciate in value of the coming years as the world is waking up to the importance of protecting nature as a way to fight the fast-accelerating climate crisis. The Robin Hood tax would be ideal as it would deliver more than 10 billion USD per DAY to climate funds, but is politically difficult to realize.

The green bonds and NC&CFs would provide a return on investment and be de-risked by guarantees from governments, philanthropy, investment programs and so on, to make them investment-grade for bundles of aggregated projects for pension funds, hedge funds, reinsurers and sovereign wealth funds as well as for smaller denominations for individual investors who would like to see their

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[21] https://wedocs.unep.org/bitstream/handle/20.500.11822/37919/NatureG20.pdf
[22] https://medcraveonline.com/IJBSBE/IJBSBE-09-00237.pdf
[23] https://en.wikipedia.org/wiki/Robin_Hood_tax

money work for a liveable future. The investments in these projects will be able to bring a return of investment through a combination of elements in the range of 5-10% per annum depending on context and risk profile. The massive investments will trigger many co-benefits and second round stimulative effects.

*Green Bonds* are already issued by governments, municipalities, and corporations to finance regenerative projects, but the scale is not large enough yet. In this case, these bonds could specifically target the restoration and sustainable management of productive landscapes, with possible collateral carbon credits harvested over a period of 30 years. Carbon Credit mortgages could work on a similar basis with loan and interest paid back over time based on carbon sequestration within a project. Mutual funds could be set up to de-risk investment in individual projects. Environmental Impact Bonds could be issued like traditional bonds but with a twist. Investors would be paid back with interest if the environmental outcomes of the funded projects meet or exceed expectations.

Special funds to guide the transition in agriculture are required everywhere These would be funds that demand investment in sustainable and resilient farming practices such as to enhance biodiversity, the sequestering of carbon, the regeneration of small water cycles to water and cool the Earth and which boost food productivity. By that means, production could be diversified while, simultaneously, helping to develop other products from the bioeconomy.

The regeneration of the planet is an investment in our collective future, and as such, needs to be backed by the right financial tools. By developing financial instruments that promote and reward regenerative practices, we not only create a business case for environmental stewardship, but we also drive the innovation needed to build a more sustainable and resilient global economy. It is time for the financial world to align its strategies with the imperative of planetary health and wellbeing, for our sake and for future generations.

## Understanding the Magnitude of this Investment Opportunity

This proposed investable market for regeneration could become the largest investment opportunity in human history because it fundamentally transforms the existing model. Instead of an exploitative system that degrades the planet and threatens the viability of all species, it proposes an economy that is permanently sustainable, catering to the needs of all people while respecting the rights of other species and nature.

Currently, the global economy operates on principles that often prioritise short-term gain over long-term sustainability. This has resulted in unprecedented environmental degradation, climate change, and loss of biodiversity, putting the future of the humanity at risk. By shifting the economic model to one that rewards regeneration and sustainability, we not only protect the planet but also create a vast array of investment opportunities.

The scale of the challenge – and thus the potential investment – is immense. It involves transitioning to renewable energy, implementing sustainable agricultural practices, restoring degraded ecosystems, managing water resources, restoring the health and productivity of the oceans, making sewage treatment worldwide circular and much more. The demand for capital to finance these transitions is massive, making this potentially the largest investment opportunity ever. The creation of an investable market for regeneration offers an opportunity to align our economic system with the long-term health and sustainability of our planet and above all avert the collapse of complex globally interconnected societies. It represents not only a potential good or even great return on investment, but also a chance to ensure a liveable future for all species, including our own. This transformation represents an investment opportunity of unprecedented scale, one that potentially is the largest in the history of humanity. But for that we need to get a new operating system of the global economy, based on the amazing technology of the internet and artificial intelligence, working very soon for this new sustainable economy to emerge everywhere.

## Appendix: The Numbers Do Add Up!

In 2007, Anastassia Makarieva and Victor Gorshkov of the Peterburg Nuclear Physics Institute elaborated the original theory for the functioning of a biotic pump which, according to them, would enable the watering of contiguous rainforest, even thousands of kilometres from the oceanic source of humidity, such as is the case in the Colombian Amazon, some 3,000 kilometres distant from the tropical Atlantic Ocean of the same equatorial latitude. (Makarieva, A., Gorshkov, V., 2007).

Since the initial elaboration of the biotic pump theory, in 2019, Peter Bunyard, together with Martin Hodnett and others, confirmed from a large series of physical experiments that water vapour condensation must lead to air flow and its circulation. From their experimental results, which involved using a dedicated chamber, they determined that the abrupt reduction in partial pressure from water vapour condensation, as the air passed over cooling coils, was one thousand times more powerful than the change in air density brought about by the cooling. That buoyancy change, therefore, had no more than a small effect on the airflow, as could be seen when condensation caused an updraught against the gravitational sinking of colder and therefore denser air. (Bunyard, P. P., Hodnett, M., *et al*., 2017 & 2019) (McIlveen, R. 2010).

But how much will reafforestation actually cool the Earth? In fact, we have discerned that forests cool the Earth's surface and the lower atmosphere in *seven distinct* but interconnected ways, as elaborated below.

1). Transpiration at the surface cools the leaves as liquid water vaporises. Each gram of water requires 540 calories of solar energy (2,257 joules) to break the hydrogen bonds holding the water molecules together. Over the 5.2 million square kilometres of the Legal Amazon of Brazil, evapotranspiration absorbs 41 per cent of the sun's energy with 98 watts absorbed per square metre versus 239 watts of sunlight received on average per square metre of the forest surface.

2). The closed-canopy rainforest shades the surface below from direct sunlight. The humidity remains high under those circumstances, preventing the surface soil from drying out excessively. Temperatures remain several degrees (Celsius) below those above the canopy. As Hodnett and his associates have shown from their research in the Brazilian Amazon, during the dry season, the soil under the rain forest dries significantly, but not usually to the point when the forest suffers. That finding indicates that the forest continues its evapotranspiration using its deep roots to tap at least down to the unsaturated zone, if not to groundwater, which close to Manaus maybe as much as 30 metres down. As a result, after a long dry season, the soil profile shows greater drying beneath the forest than beneath pasture, largely because trees have deeper roots than grasses. In fact, in order to protect its low albedo leaves from direct sunlight during the dry season, the forest must transpire or the leaf temperature will rise to the point of scorching. In drought conditions, as during the unprecedented ones of 2005, 2010 and not least 2023/2024, the forest trees may suffer severe die-back and even death. Under those circumstances, evapotranspiration will be severely reduced over the affected forest and the biotic pump from that region will also fail. (Hodnett, M.G., *et al.*, 1996).

3). The water vapour from evapotranspiration (18 grams per gram-molecule) is lighter than the nitrogen (28 per gram-molecule) and oxygen (32 per gram-molecule), which make up the bulk of air, and the vapour therefore rises through the column of air, spurred on by the warmth of the Sun over the forest canopy. The energy, encapsulated by the vapour in the form of latent heat, gets carried up to altitudes several kilometres above the Earth's surface, where colder temperatures cause the vapour to condense into clouds (an environmental lapse rate of $6.5^0$C reduction per km rise in altitude). In fact, the further from the

Earth's surface the colder it gets and the more rapid the rate of condensation. Water-vapour saturation, according to Clausius-Clapeyron, increases exponentially with temperature and colder air holds exponentially less vapour than warmer air. (Mcllveen, R., 2010) (Daniels, F. and Williams, J., 1966).

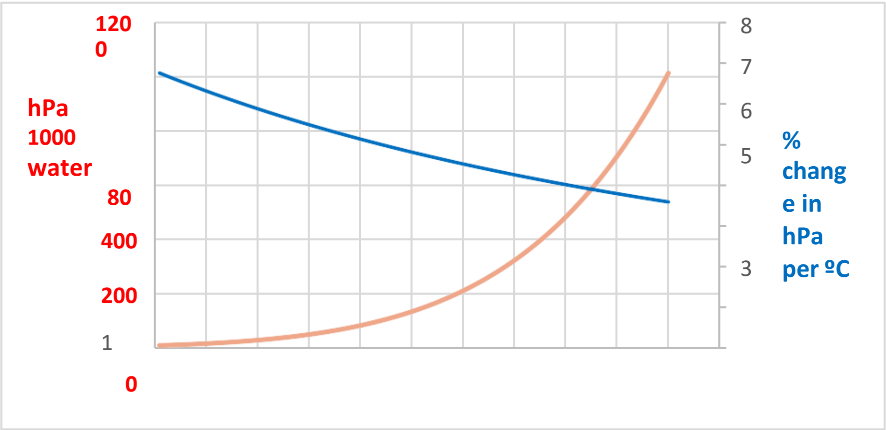


**Figure 64:** *Clausius-Clapeyron equation. log P2 - (Q*(T2-T1 ))/(R*T2 * T1 *2.302) = log P1 with Q, latent heat of evaporation 40.65 kJ mol*$^{-1}$ *, R, the ideal gas constant, 8.31 J K*$^{-1}$ *mol*$^{-1}$*. P2 = 1013.25 hPa, T2 = 373 K. X-axis is temperature in Celsius. – Peter Bunyard*

At cloud-forming altitudes, the air is thinner and the greenhouse gases ($CO_2$, $CH_4$, $N_2O$) are less effective than close to the surface where the air is considerably denser. The latent heat energy released, as the water vapour condenses into liquid water and ice, takes the form of sensible heat, which, on losing its heat to its surroundings by convection and conduction will become electromagnetic radiation. A proportion of that infrared radiation will immediately (and at the speed of light) pass out to Space through a radiation window. The remaining latent heat energy will warm one kilogram of the surrounding air by 2.5$^0$C for every gram of condensed vapour. At the altitude of the jet stream the warmed-up air will get carried away, out of the Amazon Basin and towards Africa and during its passage will cool down and send the radiation released out to Space. When we take into account the average precipitation over the rainforest, including that from evapotranspiration and the humidity borne in by the Trade Winds, as much as 70 per cent of the sun's energy, received at the surface of the rainforest, will be radiated to Space over time. (Harde, H. 2013).

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. If you are in Southern Spain at the height of summer, the daytime temperature may reach close to $50^0$C. The unbearable high temperature is a consequence of the solar energy remaining at the surface for an extended period. 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 hot or cold the regional surface is a matter of timing and we must thank the rainforest for helping to keep the Earth's surface cool.

4). The biotic pump, as elaborated by Anastassia Makarieva and Victor Gorshkov, is a critical component of the Earth-cooling by closed-canopy forests. In their biotic pump theory, published in 2007, the two physicist/mathematicians claimed that the high rate of evapo-transpiration generated over the rainforest and the subsequent cloud formation led to a partial pressure change, as vapour transformed to liquid, such as to pull the column of air upwards. In fact, the $H_2O$ volume reduces by more than 1,200 times as each molecule of water vapour transforms to liquid water. The abrupt change in water volume causes an implosion of sufficient force to draw in a horizontal current of surface air all the way from the same latitude ocean. The combination of ocean-derived humid air and the recycling of evapotranspired water vapour maintains the coastal level of rainfall several thousand kilometres from the coast, but only as long as the entire area is well-forested and a high rate of evapotranspiration is maintained. (Spracklen, D.V., *et al*., 2012 and Bunyard, P. P., 2017 & 2019).

The process, the biotic pump, which draws in the humid air from the ocean, is a critical factor in the watering of the continent. 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 3,000 kilometres inland, Eneas Salati and his colleagues determined that the rain was recycled at least five times across the expanse of the Brazilian Amazon, the distance from evaporation to precipitation covering on average some 600 kilometres. Salati, as has been confirmed since, also found that as much as 60 per cent of rainfall was re-evaporated by forest transpiration and that such evapotranspiration contributed to the watering of the rainforests further to the West. (Salati. E., 1987).

In their original paper, Anastassia and Victor challenged the idea that the Trade Winds flowing from Africa to the Amazon Basin were the result of latitudinal heat differences. They pointed out that the air directly above the ocean was warmer during the day than the air above the rainforest, especially once clouds had formed, and that, if it were not for the biotic pump, the air would flow from the land to the ocean and not the other way round.

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 ($Px$) is equal to the precipitation at the coast ($P_O$) multiplied by the minus exponential of the distance ($x$) in kilometres 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 kilometres in accordance with Salati's isotope measurements:

$$P_X = P_0 exp\left[-{}^{x}/_{l}\right]$$

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 by the 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 towards infinity. In fact, if the virtual length of the precipitation pathway of a water molecule extends to 5000 kilometres, the loss in precipitation, even thousands of kilometres 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 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 levelling off several thousand kilometres later, when the annual rainfall would be no better than that we can expect for a desert as dry as the Negev in Israel.

The biotic pump, as a physical reality, is likely to have manifested itself in full-force, once the rate of evapotranspiration had increased as a consequence of angiosperm evolution and the spread of broad-leafed trees. As to the claim by climatologists that the biotic pump theory was an incorrect explanation for the flow of surface air from the oceans to the land, Peter Bunyard and his colleagues showed experimentally that, on the contrary, the physics of condensation would invariably result in just such a flow, thereby elevating the biotic pump from theory to principle. (Makarieva, A. and Gorshkov, V., 2007 & Bunyard, P. P. *et al.*, 2019).

## Experiments Confirm Biotic Pump Theory

The scepticism 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 vapour condensation would lead to a measurable circulating airflow. He therefore designed a 5-metre square 1-metre-wide donut-shaped structure in which he could enclose local air. An industrial refrigerator attached to a 12-millimetre diameter double-layer of copper piping was used to cool a portion of the enclosed 20 kilograms of air (see below).


**Figure 65:** *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 vapour 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 10PC and a gain in density of 0.05 kilograms per* $m^3$ *– Peter Bunyard*

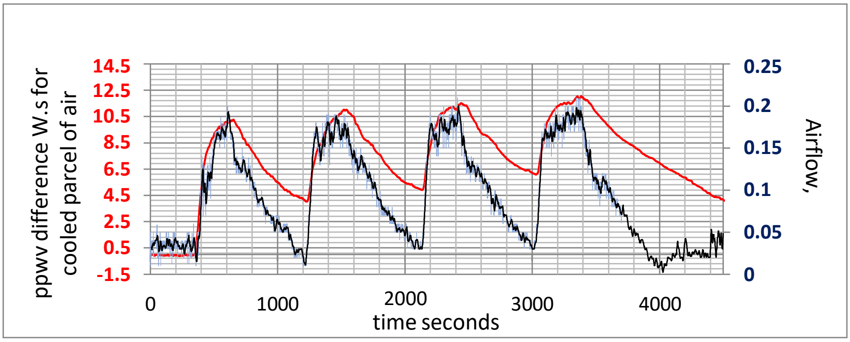


**Figure 66:** *Experiment June 27th, 2016. The graph shows 4 refrigeration cycles. The left-hand axis shows the partial pressure change in water vapour in watt-seconds during the refrigeration cycle and the right-hand axis shows the anemometer readings in metres per second. More than 100 experiments gave results similar to that shown above. - Peter Bunyard*

The results of more than 100 experiments under different external weather conditions, ranging from temperatures as high as 25$^0$C and low as 5$^0$C, with different relative humidities, indicated that condensation caused by the refrigeration at the coils of a small parcel of air inevitably led to measurable airflow. The correlation between the two phenomena, airflow versus partial pressure change from condensation indicates a significant tight fit as seen in Figure 47. Should the relative humidity be low, for instance below 60 per cent, 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$^0$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.

The energies involved in condensation-implosion are considerable. Over the Brazilian Amazon (5.2 million square kilometres) they amount to 66 watts per square metre if delivered over four hours in the mid- to late-afternoon. That is sufficient energy to cause an air current of 10.5 metres per second, strong enough to account for the Trade Winds. (McIlveen, R., 2010) (Bunyard, P. P. *et al.*, 2019).

5). The dense cumulo-nimbus clouds which form, mostly in the mid to late afternoon, over the tropical rainforest have a relatively high albedo and will 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 hours from midday to late afternoon, that would add an average cooling effect of some 30 watts per square metre and would amount to an average 12.5 per cent cooling of the total surface sunlight received during 24 hours. The forming of clouds over the tropical rainforest, plus the export of latent heat energy from evapotranspiration, could result in as much as 80 per cent of the total daily solar input to the Earth's surface being returned to Space, hence close to some 200 watts per square metre of the average 240 watts per square metre received from the Sun. (Bunyard, P. P. simple calculations, 2023).

6). As regeneration takes place and the forest grows back into degraded areas, the ratio between sensible heat and latent heat (the Bowen Ratio) will be greatly reduced. The sensible heat fraction is the fraction affected by the greenhouse gases and, in the main, is the cause of the global warming which is now taking place. Therefore, the reduction in the Bowen Ratio, as evapotranspiration kicks in, will have an important cooling effect over and above the forming of reflective clouds and the transport of latent heat to cloud-forming altitudes. (Ban-Weiss, G. A., *et al.*, 2011).

7). Clearly the regeneration and growth of the rainforest would act as a biomass sink for $CO_2$. The Amazon rainforest absorbs one-fourth of the $CO_2$ absorbed by all the land on Earth. Degradation and deforestation have resulted in the Amazon Basin becoming a source of greenhouse gas emissions rather than a sink. (Heinrich, V. H. A. et al. 2023). Nevertheless, regrowth has to result in biomass-forming and $CO_2$ uptake. In terms of cooling, hydrology is far more important, by means of latent heat transfer and reflective cloud-forming than is $CO_2$ uptake. However, once a forest spreads and matures, the uptake has the effect of sustaining long-term cooling by reducing significantly the $CO_2$ concentration in the atmosphere.

According to Jan Pokorny and his colleagues, the growth of vegetation in the temperate zone adds 1 kilogram of dry matter per year per square metre. The photosynthetic energy required to produce that 1 kg of biomass is 4.4 kilowatt-hours (kWh), equivalent to 16.1 million joules and 0.5 Watts per square metre. Meanwhile, the energy required for transpiration amounts to approximately 98 joules per square metre, or close to 200 times as much. On the basis that at least 75 per cent of that latent heat transpiration energy is radiated outwards to Space when the water vapour condenses, we conclude that, for global cooling, transpiration is far more effective 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, M., *et al*., 2012).

## 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 Watts per square metre of the Earth's surface. The Earth's surface in square metres amounts to 510 million-million square metres ($5.1x10^{14}$). Therefore, the additional global warming of the total Earth surface over the course of a year amounts to the seemingly gigantic number of $2.91109x10^{22}$ watts. Taking just the latent heat capture of the Amazon rainforest encompassing 5.75 million square kilometres and assuming all that energy is dissipated to Space, we obtain the number $2.92025x10^{22}$ watts. That number is remarkably close to the extra warming. Theoretically, and adding in the cloud-cooling effect described in 5), 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 Watts per square metre by close to half, thereby reducing the average surface temperature by $0.9^0$C. We could achieve that by restoring an area of tropical rainforest by 2.8 million square kilometres. Already more than one quarter of the Amazon rainforests have 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.

Finally, our claim that the Trade Winds depend for their directionality and strength on a functioning biotic pump gains some credence from the weakening of the Winds during the non-El Niño years of 2005 and 2024, during which the Amazon Basin suffered severe drought. In 2005, the rainfall over the Basin was down by 300 millimetres from the average annual 2,250 millimetres. The decline means that the latent heat export from the forest surface reduces by 21.5 joules per square metre compared to the 161 joules per square metre of a normal non-drought year. The NASA overheating indicates that the Earth is warming on average by 1.81 watts per square metre. Assuming that the overheating is causing a $1.5^0$C average rise in temperature, the loss of cooling over the Amazon Basin during the 2005 drought will cause an average rise in temperature over the Earth's surface of $0.25^0$C. That calculated temperature rise conforms to that shown in Figure 35.

Meanwhile, the weakening of the Trade Winds during Amazon drought-years could result in as much as the equivalent latent heat energy of 5 atomic bombs per second remaining over the tropical Atlantic Ocean compared to 'normal' years when the Amazon biotic pump is functioning and that energy is transported in the form of water vapour to the South American landmass. The extra energy remaining in the tropical Atlantic during drought years like those of 2005 and 2024 will serve to spawn powerful hurricanes like Katrina (2005) and the spate of those hitting the United States in 2024.

## Appendix: Solar Energy and Rainforest Cooling plus Clouds and Winds

Hereunder we sum up the most important quantities we used in doing the cooling calculations of the rain forest:

ET average 1.37m/yr across Amazon Basin Rainfall 2.25 m/yr across Amazon Basin Solar at Earth's surface is $3.85 \times 10^{24}$ joules Earth surface square metres = $5.1 \times 10^{14}$

NASA overheating (radiation imbalance/sq. m = 1.81 $W/m^2$

NASA overheating per Earth's surface/yr = $2.91109 \times 10^{22}$ watts

5.2 million square kilometres Brazil Amazon 1 $cm^3$ (cc) = 1 gram water

Latent heat = 540 calories/g water = 2,257.2 joules

Implosion condensation energy per gram water = 153.5 joules Sunlight received per sec per sq. m over Amazon = 239 watts

ET @1.37 m/yr per sec per sq. m over Amazon = 98 watts = 41% sunlight

Adding on 0.88 m/yr imported humidity (2.25-1.37), total latent heat/sec/sq. m = 161 watts Total latent heat of 2.25m/yr in proportion to solar = 67% sunlight

If all latent heat over legal Amazon irradiated to space the cooling effect = $2.6409 \times 10^{22}$

i.e. The total overheating is practically equal to the cooling effect of 5.5 million square km of tropical closed canopy rainforest.

To reduce the overwarming by half or $0.9^0$C would require the latent heat transport to Space of 2.25 million square km of tropical closed canopy rainforest. Implosion energy per sq. m (Amazon Basin) if delivered over 4 hours = 66 watts Airflow resulting from the implosion energy (W = 0.5 airmass*v2) = 10.5 m/s Airflow = Trade Winds flow = Biotic Pump surface airmass ocean-to-continent.

Cloud cooling over Amazon per square metre average = 30 watts per square metre Percentage cloud cooling if 75% cooling over 4 hours each day = 12.5%

Latent heat cooling @160 watts per square metre percentage = 67%

Total cooling on average = 80% or equivalent to 190 watts per square metre.

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