# Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

Peter Paul Bunyard Rob de Laet



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### Contents

Preface	i	
Acknowledgements	ii	
Introduction	1	
Chapter 1 How to Uncook Our Planet!	4-11	
Part I: The Science		
Chapter 2 Honoring the Earth's Protective Shield	13-27	
Chapter 3 What is Climate, Really?	28-48	
Chapter 4 The Magic of Life, Photosynthesis and our Future	49-51	
Chapter 5 Climate Chaos Will Curse your Future	52-60	
Chapter 6 The Amazon: Its Vital Role in Moderating the Climate	61-82	
Chapter 7 Cooling the Planet with Plants	83-98	
Part II: Challenges and Solutions: The Recipe Book		
Chapter 8 Regenerate the Great Forests and Grasslands	100-108	
Chapter 9 Rehydrate the Lands by Restoring the Water Cycles	109-123	
Chapter 10 Restoring the Oceans	124-138	
Chapter 11 Substantially Sequestering Atmospheric Carbon	139-143	
Chapter 12 Can We Slow and Reverse Sea Level Rise?	144-152	

Chapter 13 Reforming Global Food Production	153-161	
Part III: How We Can Solve the Climate Mess within Our Lifetime		
Chapter 14 It Is High Time to Change the Operating System of the World	163-184	
Biography of authors	185-186	
Disclaimer (Artificial Intelligence)	187	
Index	188-189	

Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years
Preface

#### PREFACE

To address the climate crisis, now demonstrably causing havoc with life-killing extreme events, we must not only transform our economic and societal models towards sustainability and resilience, we must have a more holistic understanding on what climate really is.

Based on James Lovelock's Gaia Theory, a world view also prevalent in many Indigenous cosmologies, we operate from the hypothesis that the Earth functions as a living organism, with ecosystems maintaining conditions for life to thrive. This book presents an in-depth look at the workings of the atmosphere in the context of a living planet and particularly the role of water, based on an earlier book written by Peter Bunyard, called Climate Chaos, published in Spanish in 2010.

The biosphere interacts with soils, water and the atmosphere to stabilize weather and cool the planet. The destruction of ecosystems disrupts these metabolisms and cycles, significantly contributing to global warming. Restoring the damaged biosphere and transitioning to sustainable food production and land use can stabilize weather and cool the planet remarkably quickly. The approach in *Cooling Climate Chaos* offers effective climate solutions. We have seen climate restoration in smaller areas. If implemented wholesale by people everywhere based on local context, it will resolve most of the climate crises worst effects within decades, while benefitting society in many ways, including the protection of biodiversity, and correcting the gross inequity of our times. It may even open the possibility of slowing down partly inevitable sea-level rise.

While reducing emissions is crucial, repairing nature and water cycles is every bit as important. Regenerative agriculture, agroforestry, and ecosystem restoration can help achieve a balanced climate, mitigate extreme weather, and sequester CO<sub>2</sub>. By leveraging these strategies, we can restore the planet's natural balance, creating a sustainable and abundant future.

Onward to a livable planet!

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

- Edward O. Wilson

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Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years Acknowledgements

#### ACKNOWLEDGEMENTS

This book is the culmination of years of research, and countless conversations about the most pressing challenge of our time, namely the existential crisis now facing humanity because of climate change. The concern for humanity's destructive impact on the natural world began 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 wrote in 2010, while he was in Colombia, called *Climate Chaos*.

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, who still has to be acknowledged as one of the greatest of all times 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 finally, Eliza Collin, who helped with research for this book, with editing and getting it published. The second part of this book emerged from a writing group within the *EcoRestoration Alliance*, a global network of scientists, earth stewards, storytellers and grassroots leaders dedicated to restoring degraded lands and waters, to promoting biodiversity, and to cooling the planet. Contributing authors have been mentioned where applicable.

Many thanks to the following people who have added their knowledge and wisdom to the emergence of this book in conversations, publications and in some cases as co-authors of some of the chapters.

In no particular order, many thanks to: Ed Huling, Jim Laurie, Walter Jehne, Michael Pilarski, Russ Speer, Stephanie Mines, Charles Eisenstein, Daniel Pinchbeck, Ousmane Pame, Rodger Savory, Antonio Nobre, Carlos Nobre, Germán Poveda, Anastassia Makarieva, Douglas Sheil, Jim Laurie, Alan Savory, David Ellison, Douglas Sheil, Zuzka Mulkerin, Michal Kravčík, Jan Pokorny, Judy Schwartz, Alpha Lo, Erica Geis, Duane Norris, Sue Butler, Ananda Fitzsimmons, Elizabeth Herald, Howard Dryden, Colin Grant, Bru Pearce, Brian von Herzen, Anamaria Frankic, Tom Goreau, Stefan Schwarzer, Christopher Haines, Richard Betts, Zac Goldsmith, Ben Goldsmith, Alexander Goldsmith, Martin Hodnett, Rafael Mantilla, Martin von Hildebrand, Phoebe Barnard and Atossa Soltani.

We thank you, the reader, for your interest and willingness to engage with this critical topic, we need all of you to step into leadership and lead the way to a sustainable future on this amazing planet.

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years Acknowledgements

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.

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#### Peter Paul Bunyard <sup>a\*</sup> and Rob de Laet <sup>b</sup>

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#### INTRODUCTION

Greenhouse gases heat up the planet, but they are not the major driver of climate change. While carbon gets all the attention, there is another huge factor which is largely overlooked. It is 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 the climate and bring about cooling.

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! 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 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 degrees C limit of rising

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temperatures, set by the IPCC as the point beyond which climate change and the extremes will become 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 the beneficial changes will result in the Earth cooling, while simultaneously countering 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.

There will be in-depth chapters based on Peter Bunyard's amazing 2010 book *Climate Chaos: Threat to Life on Earth*, to explain the scientific underpinning of the solutions the book wants to offer. (*Caos Climático: Calentamiento global, efecto invernadero y otros factores que amenazan la vida.* Grupo Editorial Educar, 2<sup>nd</sup> edition 2011. ISBN: 978-958-05-1306-3).

The second part of the book came out of a six-month writing group of the *EcoRestoration Alliance*. The group came together to write a blueprint for a complete regeneration of the Earth's biology to restore its metabolisms, and temperature regulation. All biomes can be restored fast. Collectively we have the knowledge. Part II is a summary of that blueprint. You will find the contributing authors at the top of every chapter where applicable. Many of them are renowned authors, scientists and practitioners in their own right.

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 the 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, sung by a chorus of children in the Mezquita of Córdoba during a live performance of Paco Peña's *Requiem for the Earth*, which expresses the heartfelt pain and anguish of the young upcoming generation, who unwittingly have inherited a terribly damaged Earth. So, do listen! We hope that the knowledge in this book will contribute to reversing the existential threat now facing all mankind.

Requiem for the Earth, the Children's Song, Paco Peña and Peter Bunyard

https://youtu.be/boUu4pPfR6w

### ALABANZA: RÉQUIEM POR LA TIERRA

Ay! de tí, hombre villano, ¿Qué has hecho con la tierra? ¿Dónde están las florestas, Los límpidos arroyos, el transparente mar? Has truncado la vida al árbol que, orgulloso, de la tierra salía.

Has pelado montañas; y los ríos majestuosos hoy ciénagas serán. Ahora llegan torrentes que desbordan el río y arrasan la ciudad. Las casas, el ganado, hombres, mujeres, niños todo perecerá. What of you, uncaring Man What have you done with the Earth? Where are the forests, The limpid streams, The transparent sea? You have truncated the life of the tree which, With pride, rose up from the Earth.

You have laid bare mountains, And the majestic rivers Today become unpalatable swamps. Now, we bear the brunt of torrents Which burst the banks of rivers And wipe out the city, Houses, cattle, men, women, children. If we don't take care of our Sacred Mother, all will perish.

### How to Uncook 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 saving 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.



Fig. 1. Rob de Laet & Dall-E

#### 1.1 YOU AND I ARE PART OF A LIVING PLANET

We actually have an even more important message and that is that we operate from the knowledge that our planet is alive. Indigenous cultures across the globe, including Native Americans, Aboriginal Australians, Andean and Amazonian peoples, as well as 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 supra-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.

## 1.2 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 to restore their areas focusing on natural boundaries: bioregions and watersheds and cooperate with communities in those areas to improve the situation quickly, involving as many people in the region as possible.

#### **1.3 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."



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

#### 1.4 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.



Fig. 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 have formed communities to protect sources, forests, biodiversity, and water management together based on a cooperative organisation structure, involving everyone 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.

## 1.5 THE LARGE EMERGENCY PRIORITIES TO REVERSE CLIMATE CHAOS FAST

This is the list of points we think need to be addressed immediately and at the size that fits the challenges:

- Avert the tipping point of die-back of the Amazon rainforest and strategically reforest the biome to restore the full vigour of the biotic pump function over the area, leading to fast regrowth of vast forest areas in the Americas. 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 as the whole world will be affected if this cooling organ of the planet dies back.
- 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, and 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.



Fig. 4. Healthy Amazon Rainforest – Photo of Theo Tarras/Shutterstock

- Plan to **green the desert areas** from the Thar desert to the Sahara and the fast drying out of the Mediterranean through strategic ecosystem regeneration, with the aim of drawing the Indian monsoon moisture streams all the way to the Mediterranean while simultaneously connecting them with the West-African monsoon. This will also increase precipitation on 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.



Fig. 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 do not know how best to do that but the idea is to use *nature-based-solutions* combined with technical interventions.



Fig. 6. Sea Ice in the Weddell Sea – Photo of Steve Allen/Shutterstock

#### 1.6 GLOBAL ACTION

While restoration can and must be done everywhere by everyone, these large projects we described above need 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:

- 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, regenerate degraded soils and substantially increase living biomass. A plan for this has been written. Estimate cost 0.3-0.5% of Global GDP per year for a period of twenty years.
- 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 own economy and well- being.
- To bring about a programme of ocean and coastal marine ecosystem restoration. The 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, and almost all

parts already exist. The cost to launch the first viable product is 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. As we describe in a later chapter, the transition of an area of 2.5 million square kilometres in the tropical belt from what was once a closed-canopy forest back to forest, combined with strategically-sited agroforestry, will increase the cooling capacity through the atmospheric water cycle sufficient to stop the planet from heating up further.

Frontloading vigorous protection and repair of nature around the world together with massive increases in regenerative agricultural practices and agroforestry will make landscapes climate resilient. Combined with reviving ocean biology, land-based initiatives will restore a balanced climate, calm the weather and cool the planet! This action, involving large parts of the global population in all kinds of different roles, is the only possible way out of the clear path leading to the collapse we are on now. If you resonate with these words, step into leadership and find your role in the greatest endeavour ever undertaken by humanity.

This book, *Cooling Climate Chaos*, 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.

The initial chapters are dedicated to taking a look at 3.8 billion years of evolving life and unravelling the interconnections between these systems and how human activities have disrupted the natural balance. As the book progresses, it shifts focus to practical solutions, presenting practical strategies, from local actions to large-scale initiatives, to reverse the damage caused by our destructive economies. Packed with actionable tips, innovative ideas, and inspiring case studies, this guide empowers readers to become active participants in restoring Earth's climate. Whether you're a student, a policy maker, a company CEO or a concerned citizen, "*Cooling Climate Chaos*" offers a full proposal to restore the future. So, let's first dive into the science of the living planet to understand the roots of our proposals.



# Fig. 7. Atmospheric and Ocean CO<sub>2</sub> values over time, indicate inverse correlations between phytoplankton and CO<sub>2</sub> – Graphs by Peter Bunyard from the Plymouth Marine Biological Laboratory.

#### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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## Part I: The Science

### 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.



## Fig. 8. Sunrise over the planet showing how thin is our protective atmosphere. Courtesy: NASA

The Earth is the only place we know where life thrives in the cosmos. The incredibly beautiful biosphere has been responsible for creating the atmosphere as it currently is, with its composite of nitrogen, oxygen, water vapour and greenhouse gases. If life had never been and had not transformed the atmosphere into what it is today, living forms such as ourselves could never have evolved and survived. Without question, we humans inherited the best of all possible worlds, because life, prior to our hominid evolution, had made it so. The layer of atmospheric gases, carefully managed by Nature and which we inherited, plays a critical role in safeguarding the planet and its multifarious inhabitants, day and night.

#### 2.1 A Bit of Astrophysics and Planetary Science

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

In addition, the ionosphere, a layer of the atmosphere populated with charged particles, interacts with the magnetic field and solar wind and aids in the deflection of these potentially harmful particles. Without such mechanisms in place, and the protective effects of the Earth's magnetic field, these harmful rays could dramatically affect living organisms and certainly would not allow for such abundance of life including ourselves. The Auroras, whether in the high latitudes of both hemispheres, give us a spectacular view of the interaction of solar and cosmic radiation with our protective atmosphere. Apart from all this, the atmosphere forms an effective barrier against incoming space debris, such as small meteors, which, upon entry into the Earth's atmosphere, burn up because of their high velocities and the friction generated as they pass through the air. The outcome of this process, visible as shooting stars, protects the Earth's surface from continuous impact. That said, the atmosphere does not protect against the rare event of being struck by very large meteors. The last mass extinction on Earth was caused by the impact of a large meteor, the size of Mt Everest, which famously led to the extinction of large dinosaurs some 66 million years ago during the Cretaceous period. The event happened near the current town of Chicxulub in the Yucatan Peninsula, Mexico. It had a devastating impact the world over. The Moon, too, is the result of a planetary collision, more than 4,000 million years ago, which caused the fledging Earth to spew it out. We are indeed fortunate to have the Moon, for the very reason that it acts like a gyroscope, keeping the Earth from tumbling in its orbit around the Sun, which, were it to do so, would result in wholly chaotic seasons and would have prevented the evolution of life as we now know it.

For the most part, the atmosphere is a wonderful blanket of protection that lets through the right amount and right type of energy from the Sun for Life, as we know it, to be sustained. In addition, the atmosphere, with its greenhouse gases and especially water vapour, is a fundamental regulator of temperature on our planet. Water, as vapour, is the most potent of the atmosphere's greenhouse gases yet, when it condenses into dense white clouds, it becomes an agent of cooling by reflecting sunlight back to Space. What is happening to the water-cycle because of deforestation and human-induced environmental transformation is undoubtedly one of the key issues related to what we are experiencing as climate chaos, with horrifying increases in the frequency and intensity of extreme weather events.

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.



## Fig. 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.

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 degrees Celsius (260 degrees Fahrenheit), while on the lunar night-side temperatures as low as minus 173 degrees Celsius (minus 279 degrees Fahrenheit) have been observed. 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 without an atmosphere, like what scientists call a 'black body' and imagine that it is January when Antarctica is having its summer and the North Pole its winter. The temperature at the North Poles would be -140°C and in Antarctica +40°C. With the atmosphere, that sharp contrast between the two Poles is smoothed out and the temperature is not so different from one to the other, despite the seasonal shifts in exposure to the Sun.

In essence, the Earth's atmosphere, through all these functions, works continuously to protect the planet and its abundance of life from external threats and to maintain conditions suitable for life. Many of these functions have been developed by life during the billions of years of evolution and it is life itself that carefully calibrates the temperature through the power of photosynthesis, evapotranspiration, cloud, rain and wind production with clear differences

depending on how much solar energy reaches the surface. Much more energy, approximately double, is received at the equator during the course of a year, than at the poles.



Fig. 10. Actual and calculated temperature if there was no atmosphere – Graph Peter Bunyard

#### 2.2 HOW HUMANS CHANGED THE ATMOSPHERE

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 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, water resources, all ecosystems, human health, and 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.

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years



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

But while humans and many species with which we are familiar, like the big mammals, may not be able to adapt to the changes on the planet, if given time, meaning thousands of years, and left to its own evolutionary devices, Nature as a whole will recover and grow anew. Only a hundred million years ago, the temperature on Earth was 7°C higher on average than now. Moreover, the planet had no ice caps, sea levels were 70 metres higher and life, thank you, was doing pretty well. So, let us be clear, human-induced climate change does not pose a significant threat to life as a whole, in fact the authors of this book believe that Nature will probably bounce back within a matter of decades should global human societies collapse under the global deterioration of life-conditions on Earth. Indeed, we have some circumstantial evidence that points in that direction: the short cold period in the 16th and early 17th century in Europe, also known as the Little Ice Age, was in all likelihood in part triggered by events on the other side of the planet. in the so-called New World. As we all know, the population of North America collapsed because of the bacteria and viruses which the early European colonists brought to the continent. This collapse caused the death of 90 percent of the indigenous population of some 50 to 60 million people, who largely depended on agriculture. With a much reduced and sick population, agriculture was largely abandoned and the forests grew back, triggering a cooling of the climate. (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 same negative 'cooling' feedback will kick in should our numbers drop dramatically as a result of the collapse of our societies because of climate change

wiping out the means to grow sufficient food, whether from excess heat, lack of water, loss of fertile soils and a COVID-like disease for which we fail to find the cure.

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

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

With our concern about the rising levels of greenhouse gases in the atmosphere, we must be aware that we need sufficient greenhouse gases to make our planet comfortable for the plethora of species which make up the biota. The warming of the atmosphere, because of the greenhouse gases, including the important greenhouse characteristics of water vapour, has taken the planet's average surface temperature from minus 18°C to plus 15°C (the average of 200 years ago), a warming of 33°C on average. That is the average surface temperature we inherited at the beginning of the industrial revolution. We have now increased the global temperature by just 1.4°C, which is the combined result of greenhouse gas emissions from fossil fuel burning and from our destruction and degradation of essential ecosystems, especially forests, and just that seemingly small rise in temperature has led to the spate of extreme climate events which we are currently experiencing, including the heat waves and outbreaks of fires that devastated Greece and elsewhere across the Northern Hemisphere during July 2023.

Given from our point of view that our greenhouse gas emissions are warming the planet excessively, we endorse initiatives to phase out the burning of fossil fuels, whether used in electricity generation, in transport or heating houses. However, the notion that we can solve the climate crisis simply by reducing  $CO_2$  emissions while capturing carbon from smoke-stacks is missing the point that natural ecosystems are absolutely critical in giving us a climate which is beneficial to us and life in general. If, in averting climate chaos, we do not widen our minds and actions to the wider story of how climate chaos and the heating up of the planet have come about, we will be responsible for the collapse of our societies simply because our diagnosis was only right to a small extent.

By far the largest impact on climate, for which we are responsible, has resulted from extreme land-use change and the destruction of ecosystems. That worldwide

destruction has altered drastically the flow of water vapour from its evaporation and precipitation, all of which has had a profound effect on atmospheric hydrology and the flow of water locally and globally from ocean to land and back to ocean. The transformation of water through its phases from ice and liquid to vapour and back to liquid is the Earth's major transporter of the Sun's energy from the Earth's surface to outer Space, and we have to thank this fundamental role of water in cooling the planet. And, that cooling has taken place despite the Sun being 30 percent more luminous and energetic than it was 4.5 billion years ago when the Earth first formed. The increased luminosity of the Sun is the result of the retention of solar heat as helium accumulates from the thermonuclear fusion of hydrogen, with helium acting as a greenhouse gas blanket.

Life, during its long history on Earth, evolved photosynthesising-vegetation, whether trees on land or phytoplankton in the ocean. Cloud-forming over both land and ocean has been significantly enhanced because of transpiration and because of the emission of aerosols, such as dimethyl sulphide and terpenes, all of which are excellent cloud-condensation nuclei. In effect, the evolution of life on Earth has gone hand-in-hand with the regulation of the Earth's surface temperature, both by regulating the flow of water and by forming biomass from atmospheric  $CO_2$  such that it has never become too hot or too cold, even taking account of cataclysmic events like the Chicxulub meteor strike 66 million years ago.



Fig. 12. Without rainforests we cannot cool the Earth. Ricardo Moraes | Credit: REUTERS

We have come to the conclusion that Nature has been the key regulator of the Earth's temperature and climate mainly through the movement of water in its various forms (liquid, solid, and vapour) through the atmosphere. Atmospheric hydrology, therefore, plays a critical role in weather and climate systems. When

we take into account the relationship between water and sunlight energy, we find that as much as 90 percent of the temperature regulation of the atmosphere is done by water, and just 10 percent by  $CO_2$  and other greenhouse gases. In fact, the flow of water vapour in the atmosphere has contrasting effects on surface temperature. Atmospheric warming comes from water vapour in the atmosphere being the most important greenhouse gas; atmospheric cooling from the forming of dense, white clouds which reflect sunlight back to Space and, most importantly, from the release of latent heat energy at cloud-forming altitude, especially from high-altitude, towering cumulo-nimbus clouds, with their anvil-like shape.



#### Fig. 13. From McIlveen's book on Climate and Weather. The diagram shows the radiation released from the anvil-shaped, cumulo-nimbus cloud at 15 km altitude over the Tropics. More radiation is released to Space as the jet stream carries the air from the Equator to the higher latitudes. The forests send their transpired vapour upwards to where they form clouds on condensation.

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 in the water cycle by redirecting and storing water for irrigation, often leading to soil salinization, and altering

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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.



Fig. 14. 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. Due to the disruption of natural water cycles, land-use change has been the most important factor in causing climate chaos and surface temperatures to rise. Greenhouse gas emissions are also important, but, with deforestation rampant, the warming which accompanies such emissions can go unchecked. A wellvegetated surface and a healthy ocean, with its cloud- forming phytoplankton, will act together to temper and moderate the energy flows from the Sun. Under those circumstances, the intensity and frequency of extreme weather events will be significantly reduced.

#### 2.3 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 for each gram molecule of H<sub>2</sub>O. That implosive reduction causes the 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, creating rainfall patterns 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 implosion energy, as water vapour from evapotranspiration condenses into thick clouds, amounts to as much as the equivalent energy of one atomic bomb per second!

Following the industrial revolution of some 250 years ago, the ever-growing world population, now more than 8 billion people, has become increasingly urbanised and materialistically demanding. For the most part, the energy embedded in fossil fuels has enabled industrialisation and materialistic-living to penetrate apace to virtually every corner of the Earth. Concurrent economic activity has become a major and aggressive factor in the exploitation and destruction of natural ecosystems. An area larger than China has since been deforested and even larger areas have been degraded. Fifty-eight percent of habitable land (excluding the ice sheets and deserts) has now been substantially changed.

The consequences of widespread environmental destruction are now beginning to reveal themselves with impacts on food production and water availability in vulnerable parts of the world. Increasing numbers of refugees are fleeing for their lives from conflicts and extreme weather events. Countries like El Salvador, Nicaragua, Venezuela, several Sahelian countries, Somalia, Yemen, Syria, Lebanon and others have suffered difficult-to-reverse collapse of governing structures which were caused by a whole complex of social, economic and political factors but which all had problems with food and water security as one of its main roots. This food and water insecurity was in many cases caused by excessive land-use change, with reductions in the biological capacity to grow plants for food. The green revolution, based on crops that required massive application of chemical fertilisers and pesticides, for their added growth, may have temporarily reversed this trend but wholly at the cost of ruining the fertile soils upon which life on land has depended for tens of millions of years. The increasing blows to harvests caused by a combination of weather events like droughts, and the destruction of

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

ecosystems, has for a large part been caused by modern industrial- type food production, often replacing small-scale, labour-intensive but productive food production based on local resources. Large-scale industrial-type monoculture production of grains, soy beans, sugar cane, and cotton has been at the expense of natural ecosystems, including forests, and without doubt, has led regionally and globally to further climate chaos.



Diagram developed by Andrew Ayres.

Fig. 15. 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. The 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. –by Andrew Ayres from a discussion with Peter Bunyard.

#### 2.4 CREATING THE CONDITIONS FOR THE GREAT TURNING

"If you do not change direction, you might end up where you are heading", Lao Tzu The opportunity we have to avoid the wholesale collapse of global human society is small and shrinking by the day, but there is an outside chance that we can still turn it around once we understand that we are an integral part of a living planet and that, with such understanding, comes the responsibility of caring for a biosphere which has created the conditions for life and ourselves to thrive. Care and good husbandry for the natural world, with its essential ecosystems, needs to become our highest priority. Just as our wellbeing is in good measure determined by the bacterial flora in our gut, our future welfare is directly linked to the health of the whole planet. Imagine that you are part of a much larger living being, an organism that has been alive for hundreds of millions of years and in that time has been working constantly to improve conditions for life on Earth, including the regulation of temperature, moisture, and the necessary recycling of nutrients. This amazing web of life, with its countless species and mind-boggling interactions, has co- evolved with the surface of the Earth to make a living planet. We are now at a threshold where any further destruction of essential ecosystems, like the remaining forests, will take us over the edge and into the abyss of climate chaos, leading to a fast and sudden collapse of societies.

Caring for the Earth, the land, the soils, the plant life and biodiversity everywhere, while drastically reforming our life-styles and food production methods could get us out of the mess we are in within years rather than decades. Only by that can we avoid the worst genocide in the history of our species, or as the UN Secretary-General Antonio Guterres calls it, *our collective suicide*. The causes of the deterioration of the weather, climate, food and water security are relatively simple to understand and must be reversed fast.

Therefore, we absolutely need a widespread planetary movement to enable the Great Turn-Around. That movement must operate from a planetary perspective in the short -term before the wholesale collapse of human societies becomes irreversible.

Luckily, we have developed tools that come in very handy to avert collapse: the internet and social media have now created a web of collective interaction, knowledge and action that can make change go viral. We need to capture social media to incentivise and make the Great Turn-Around happen within a short time-frame. It can go very fast because the largest investors in the world, such as pension funds, re-insurers and sovereign wealth funds have already found out that their asset base will be degraded fast with the accelerated onslaught of climate change destabilising whole regions. Also, once a new regenerative asset class comes off the ground, it will become the largest investment proposition ever. What project is larger than restoring our planet?

Tied in with the networking of the internet, we should employ Artificial Intelligence to speed up project design and management for generating climate-resilient landscape restoration across the planet. Ultimately, the aim would be to provide local people with optimised plans for their particular bioregion to create wellbeing for all in sync with local nature.

How can we create a global movement for regeneration that captures the hearts, minds and hands of the young who right now see their future destroyed?

#### 2.5 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 in living conditions. Let's create a new powerful story where we trust the intelligence of the Earth, and 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 at 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 multicoloured, 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.

# 2.6 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 unevenly-accumulated wealth, held by few, to regenerate our planet fast and invest in the habitable world of tomorrow, based on sustainability, circularity, and vibrant ecosystems while taking care of the basic needs of all.



# Fig. 16. 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

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

the community. The economy of such communities is based on the notion of reciprocity and exchange, not only within their communities but in 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', 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 it is part of their cosmology. (Martin von Hildebrand, 1996).



# Fig. 17. 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 life force of new generations can overcome our current challenges. Once we wake up from 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 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.

## **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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# 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% 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, which it is not. 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, Milankovitch, 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, at least partially, the other, main factor, being the role of life in regulating the impact of greenhouse gases in the atmosphere. Nevertheless, nothing ever remains the same and the impact of human beings on the Earth is distorting what otherwise might well have been the trajectory of global temperature had humans not been around.

Indeed, on top of all those physical and unavoidable changes in how much sunlight the Earth receives and exactly which part of the planet is receiving it, we human beings are accelerating the process of change through our actions. In order to understand that change – anthropogenic change or man-induced change – we need to know as best as we can what it is that gives us our climate over and above the Sun's rays and the Earth's orbit, albeit that these two factors are undoubtedly critical ones.

# 3.1 THE SUN

The Sun derives its energy from hydrogen, the most common atom to be found in the Sun, being squeezed so forcibly together that it fuses at extremely high temperatures and pressures in a thermonuclear reaction to form helium and in so doing loses a little bit of mass which converts instantly into enormous quantities of energy. Here, Einstein's famous equation of mass transforming into energy and vice versa comes into play: E (energy) =  $mc^2$ , where m is mass and c is the velocity of light. As the helium builds up at the surface of the Sun, it acts like a greenhouse gas, making the Sun get hotter such that the thermonuclear reaction gradually and almost imperceptibly speeds up.



Fig. 18. Solar Input changes of seasons and the Milankovitch cycles changing weather and climate – Graph by Peter Bunyard

# 3.2 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 importantly, 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 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 17<sup>th</sup> 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

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

during periods of low sunspot activity, as happened during the Mini Ice Age of the 18<sup>th</sup> century. Then, Europe froze over during its winters, as is shown in paintings of the river Thames, with people skating happily over the surface.



Images of sunspots courtesy of NASA and the Royal Swedish Academy of Sciences

#### Fig. 19. 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 forests, 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 to when the Europeans first arrived. As we have mentioned before, the enhanced evapotranspiration from the spread of forests led to an average surface cooling of as much as 1°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, with 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.

Back to the Sun, some of the hydrogen atoms around the Sun's surface gain sufficient energy to escape the intense gravitational field, and, as atoms dissociate into protons and electrons, stream out to form the *solar wind*, a portion of which

reaches the outer atmosphere of the Earth. Physicists originally thought that the *solar wind* increased in strength during the peak of sunspot activity, but, recent observations suggest that the relationship between sunspots and the solar wind may not necessarily hold. The solar wind interacts with the stream of cosmic rays coming from outer space and the stronger the wind, the weaker the bombardment of the Earth's atmosphere by cosmic rays.



#### Fig. 20. Winter during the "Little Ice Age" - photo credit Museum of London

It is becoming clear that our planet's climate is not simply the result of how much energy the Earth receives from the Sun, but is affected by other factors, including that the Earth is a watery planet, and that when clouds form from water vapour in the lower atmosphere, they mask the Earth's surface and cause some of the Sun's rays to be reflected back into space.

Water vapour, because of the latent heat associated with evaporation (some 540 calories per gram to turn liquid water into vapour), acts to transfer energy from one place to another, as when it condenses back into liquid and releases the equivalent energy of vaporisation.

We will 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 giving 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.



Fig. 21. Different Albedo values on the planet – Graph: 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 energy 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* ismeasured on a scale of 0 to 1, or 0% to 100%. For instance, ice, snow and dense clouds, all have high albedo, while the open oceans, vegetation and bare rock have a low albedo.



Fig. 22. High Albedo snow cover in majestic winter landscape – photo Andrew Mayovskyy/Shutterstock

# 3.3 EARTH'S ROTATION

As we have pointed out, 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 age.

## 3.4 GASEOUS COMPOSITION OF THE ATMOSPHERE

The composition of the atmosphere is made up of gases which, with rare exceptions, are all part of life's metabolism. As we have discovered as a result of scientific research over the past century, life has played a hand in regulating the concentrations of gases in the atmosphere, whether they be nitrogen, oxygen, carbon dioxide, methane and nitrous oxide and, equally, plays a massive role in the way in which water gets distributed across continents. 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.

# 3.5 GREENHOUSE GASES

Typically, carbon dioxide (CO<sub>2</sub>), water vapour ( $H_2O$ ), methane (CH<sub>4</sub>) and nitrous oxide  $(N_2O)$ , have the potential to resonate with infrared photons, and since each molecular species has its own resonance frequency, the greenhouse gases cover a considerable range of the infrared spectrum. Satellites orbiting above the atmosphere indicate the extent to which the different greenhouse gases absorb thermal radiation and at what frequencies. Certain frequencies are unaffected by the presence of greenhouse gases, and those frequencies pass through the atmosphere without hindrance. Water vapour is seen to absorb infrared at each end of the thermal spectrum, with carbon dioxide making a big dent in the wavelength spectrum from about 15 to 19 micrometres ( $\mu$ m). The resonances of methane (CH<sub>4</sub>) and nitrous oxide overlap between wavelengths of 7.75 to 8.25µm and ozone has a strong resonance between 9.5 and 10µm. Altogether, the different greenhouse gases complement each other, covering a good part of the full infrared spectrum. The extent to which the atmosphere warms up depends on the concentrations of the greenhouse gases, at least up to the point of saturation, beyond which the infra-red of a particular wavelength passes out to space relatively unhampered.

Our planet is a watery planet, with two-thirds of the surface covered by the oceans. On account of the greenhouse gases, like carbon dioxide, which warms the surface through trapping infrared radiation, water evaporates, thus providing the allessential rainfall for life on the continents. Water vapour has a powerful greenhouse effect, in its totality much more because of its concentration in the atmosphere than that of all the other greenhouse gases combined. Consequently, as we add greenhouse gases to the atmosphere, from the burning of fossil fuels and deforestation, we are causing the rise in surface temperatures to bring about more evaporation of water, in particular from the oceans. That increase in evaporation will enhance the greenhouse effect, such that temperatures will rise



still further and so on, until a new balance is reached; that is assuming that we have stopped emitting more greenhouse gases.

# Fig. 23. Feedback loops in the atmosphere created by increasing water and CO<sub>2</sub> – Peter Bunyard

We are all aware of the Sun's power to burn our skins, dry out lakes and leave soil cracked and baked. If we add up the total of the energy delivered to the Earth it gives us prodigiously large numbers. In fact, the amount of solar energy getting to the Earth's surface in just one hour is equivalent to more energy than all human beings in the world use in the course of a year. In thinking of capturing that energy instead of our current reliance on fossil fuels, we have to take into account that the Sun's energy is not easily concentrated but is relatively diffuse and dispersed over a wide area. Furthermore, the amount of energy which the Sun delivers to any one place on the Earth is not constant; it varies with the seasons and the length of the day, whether it be day or night, and whether the skies are clear or covered in clouds. Yet, it would be wrong to think that the Sun does no more than shine down on us. The energy it gives to the Earth helps generate the winds and the circulation of seawater in the oceans. Wind and wave machines, in point of fact, use the Sun's energy, but at one step removed from direct sunlight, and of course, the wind

may be strong during night-time or the waves bigger and more powerful. The spinning of the Earth, in an anticlockwise direction – the Coriolis Force – contributes to air and ocean currents.

# 3.6 LUNAR ENERGY

The Moon also adds gravitational power to the Earth, causing the tides, which in some selected spots in the World, can vary by as much as 15 or more metres. Tidal energy, especially where large tides are experienced, as in Rance in Brittany, in the Bristol Channel in the UK, or Fundy Bay in Nova Scotia are therefore possible sources of power. The Rance tidal barrage has been operating since 1966 and it generates some 240 megawatts of electric power (one megawatt is one million watts) from a tidal difference which can amount to 13 metres.



Rance Tidal Barrage, France, 240 MW

#### Fig. 24. Tidal Energy Power Station in France – Peter Bunyard

Venus has an orbit around the Sun which takes it within 108 million kilometres, and which results in an average surface temperature of some 457°C. That is the temperature of a really hot, red-glowing, oven. Then we have Mars, the other flanking planet to the Earth. Mars, with its thin atmosphere, has an orbit which takes 205 million kilometres at its closest and 249 million kilometres at its furthest. The average surface temperature on that inhospitable planet is some 55°C below zero: therefore, bitterly cold. So, we have the Earth, with just the right amount of

surface heat, between its two flanking and inhospitable planets, Venus and Mars. Like Goldilocks choosing the right bowl of porridge, life appears to have selected the right planet for its well-being and indeed survival. It took the perception and scientific acumen of James Lovelock, in the 1960s, to realise that Life, or as he described it *Gaia*, at its inception, had not just inherited the perfect medium for its survival but had then adapted the Earth such that Life, in all its manifest appearances, could spread to every nook and cranny, all the while maintaining just the right conditions of temperature and surface conditions, in a dynamic interplay of positive and negative feedbacks. (Bunyard, 2022).

A comparison of the planetary atmospheres of Mars, Venus	and Earth			
	Venus	Earth with Life	Mars	Earth without Life
Carbon Dioxide (%)	>90	0.035	>80	98
Nitrogen (%)	1.9	79	2.7	1.9
Oxygen (%)	trace	21	<0.13	trace
Methane (%)	none	0.003	none	none
Water(m*)	0.003	3000	0.00001	0.003
Pressure (atm)	90	1	0.007	60
Observed surface temperature (°C)	477°	15°	-47°	unknown
Surface temperature in absence of greenhouse gases (°C)	-46°	-18°	-57°	Unknown
Warming due to greenhouse effect (°C)	523°	33°	10°	240°-340

#### Fig. 25. Comparison of planetary atmospheres of Mars, Venus and the Earth with and without Life – Lynn Margulis, *Gaia in Action: Science of the Living Earth.* Floris Books 1996)

**Nitrogen:** Some 78% of the atmosphere is made up of molecules of nitrogen, N<sub>2</sub>. Nitrogen is an essential element for life as we can see when we look at the composition of amino acids, proteins, DNA, and RNA. It is fortunate for life on the continents that so much nitrogen is in the atmosphere rather than washed out into the oceans in the form of nitrous and nitric acid. In fact, denitrifying bacteria in the oceans and on land send free molecular nitrogen into the atmosphere, in contrast to the nitrogen fixers, such as the rhizobacteria found in the root nodules of leguminous plants, which capture the nitrogen so that it can be synthesised into essential compounds for the living cell. The fixing of nitrogen needs energy – it is an endothermic reaction – and is helped by the high concentration of nitrogen gas in the atmosphere. In fact, the nitrogen-fixing bacteria, such as are found in the root nodules of leguminous plants (peas, beans, soya, peanuts), can operate only

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

when oxygen levels are low to vanishingly small and so the host plant manufactures a type of haemoglobin which mops up the oxygen in the root nodules, so giving them their characteristic rusty red colour. That relationship between the denitrifying bacteria and the nitrogen fixers helps regulate the balance of essential nutrients in the ocean, thereby keeping them in circulation for much longer than if they were to get caught up in the sediments. And what happens biologically in the oceans helps determine oxygen levels in the atmosphere. Moreover, the high concentration of nitrogen in the atmosphere helps dampen down the incendiary nature of oxygen, preventing conflagrations which would prevent trees from growing.



#### Fig. 26. Bacterial regulation of ocean nutrients - taken from Timothy Lenton and Andrew Watson, now at Exeter University. Peter Bunyard

Decomposition is the other side of the coin from synthesis and, as a cell dies and its components decay, some of the nitrogen gets oxidised to nitrous oxide, N<sub>2</sub>O. Nitrous oxide weight per weight is some 300 times more powerful as a greenhouse gas compared to carbon dioxide. However, the concentration of N<sub>2</sub>O is more than 1000 times less than that of CO<sub>2</sub>, and it makes up around 9% of total greenhouse gases (not taking water vapour into account), while CO<sub>2</sub> accounts for 72% and methane 18%.

Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years



Fig. 27. Nitrogen cycle – for it to function well, life needs a high atmospheric concentration. Graph by Peter Bunyard



Fig. 28. Nitrogen Cycle at plant level – Artist unknown, courtesy QCE Biology Revision

**Oxygen:**  $O_2$  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 ( $6 CO_2 + 6 H_2O = 6 O_2 + C_6H_{12}O_6$ ). Oxygen, in common with nitrogen, is not a greenhouse gas.

**Methane:** CH<sub>4</sub>, is mostly generated by methanogenic bacteria which survive well where there is little or no oxygen, such as in waterlogged soils and marshes and not least in the guts of invertebrates, such as termites. Ruminants, which include cattle, with their multiple stomach chambers for digesting cellulose-rich substances such as grass, are also prolific producers of methane, particularly when the vegetation is poor, as is generally the case with pasture grown on the poor soils of what once was a tropical rainforest. Cattle can be thought of as mobile 40-gallon methane generators, with each animal producing as much as several hundred kilograms of the gas each year.

After water vapour and carbon dioxide, methane is the next most important greenhouse gas. Methanogenic bacteria, with their need for oxygen-free places, such as bogs, swamps, irrigated rice paddies or the guts of animals, recall a time, more than 2 billion years ago, when the Earth's atmosphere lacked oxygen and methanogenic bacteria happily exposed themselves to the atmosphere. Once photosynthesizers had evolved and oxygen began to build up in the atmosphere, the methanogen's vulnerability to oxygen forced them into hiding.

Methanogens survive by pulling the oxygen atoms off carbon dioxide and then directing the oxygen to recombine with hydrogen or other hydrogen-rich chemicals, releasing energy in the process and fuelling their metabolism. They can also survive on acetate, methanol (wood alcohol) or trimethylamine. Methanogens therefore convert buried organic matter into the gas methane. Methane, when in the atmosphere, tends to interact with oxidising molecules, of which the most important is hydroxyl (OH). Hydroxyl derives primarily from the interaction between ozone and water. By oxidising methane, hydroxyl converts to water and in essence therefore methane removes oxygen from the atmosphere.

In what is one of the strange paradoxes of life on Earth, bacteria that shun oxygen actually help regulate oxygen levels in the atmosphere. Without methanogens, it might well be that oxygen levels would begin rising to the point when soaking-wet organic matter would be in grave danger of spontaneous combustion. Even the wettest forests in the world, like the Chocó rainforests lying off the Pacific Coast in Colombia and Ecuador, with their 12 metres of rain each year, would likely burn, were it not for those ancient Archean bacteria. 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.

Methane was present as a greenhouse gas in the pre-industrial atmosphere of 1750, but at a relatively low concentration of 0.8 parts per million in volume (ppmv)

and its contribution to surface warmth was relatively small. With an annual rate of increase of nearly one per cent, the gas has now more than doubled its concentration in the atmosphere to 1.9 ppmv from 1.8 ppmv in 2011, and 0.7 in pre-industrial times, some 200 years ago, thus exceeding its highest-ever concentration in the past 160,000 years. The methane sequence, derived from the Vostok ice core, shows interesting parallels with carbon dioxide, in that it also follows the ups and downs of temperature shifts. Warmer spells are associated with concentrations of methane of up to 0.7 ppmv and cold spells with concentrations that fall down as low as 0.3 ppmv.



Fig. 29. Atmospheric Methane increase over time in parts per billion – courtesy NOAA

## **3.7 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

While water vapour is by far the most abundant GHG in the atmosphere and responsible for most of the GHG effect overall, the per kilo measurement cannot be applied because the substance has a different impact depending on where it is in the atmosphere, how warm the surrounding air is and because it changes state from gas to liquid and ice and back again.

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.

**Potential Catastrophic Releases:** Considerable quantities of methane are trapped under permafrost in boreal regions close to the Arctic Circle. Rising temperatures, resulting in the melting of permafrost, could bring about the release of as much as 450 Gt of carbon in the form of carbon dioxide and methane. Such a release would be a powerful, runaway self-reinforcing feedback since it would entail more temperature rise, further permafrost melting and hence further releases. We already have considerable cause for concern. Siberia, much of which is covered in permafrost, is warming faster than almost anywhere on the planet.

But that is not all: according to the US Geographical Survey, 10,000 billion tonnes (GT) of methane are currently trapped under pressure in crystal structures — methane hydrates — on the edges of continental shelves, making them the Earth's largest fossil-fuel reservoir.

Should the temperature in the surrounding water or sediment be increased to the point where methane hydrate becomes unstable, methane gas could be released overnight. Hence, where water is relatively shallow and thus easier to heat, as in the Arctic (which is already warming at a rate two to three times the global average), tens if not hundreds of billions of tonnes of methane could be released. It happened before, some 55 million years ago and even more dramatically during the Permian/Triassic extinction of 251.4 million years ago when 96% of all marine species went extinct and 70% of terrestrial vertebrate species. Such massive emissions of greenhouse gases would have given rise to rapid global warming.

Methanogens and Hydroxyl Radicals: The life span of gases in the atmosphere, such as methane, depends on chemical reactions involving oxidising substances

and energy from the sun. The hydroxyl radical is generated when ultraviolet light splits ozone into oxygen gas  $(O_2)$  and an excited oxygen atom that immediately reacts with water. For every ozone molecule that splits two hydroxyl radicals are created. Much of this generation takes place in tropical skies simply because the ultraviolet of the right wavelength is better able to penetrate there, owing to low ozone levels high up in the stratosphere above equatorial regions. The quantities of hydroxyl produced by such photochemical reactions are extremely small, yet they are sufficient to account for the oxidation of methane, carbon monoxide (CO), nitrous oxide, hydrogen sulphide as well as traces of organic gases such as methyl-chloroform, emitted by industry. The hydroxyl radical (OH<sup>-</sup>) therefore plays a seminal role in cleansing the atmosphere of substances that might otherwise accumulate.

**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*.



# Fig. 30. Stromatolites are rock-like structures built by cyanobacteria colonies - Photo Ikonya/Shutterstock.

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's surface and escaped into space. Certainly, Venus, with a surface temperature on average close to 500°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°C.

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



#### Fig. 31. 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 1957, Lovelock invented the Electron Capture Detector (ECD), a clever tool for measuring trace contaminants such as chlorofluorocarbons which, as refrigerants and propellants for aerosol sprays, were beginning to become widely used in the industrialised world. The device used a radioactive isotope of nickel to provide electrons as beta radiation which then interacted with nitrogen gas to generate a

measurable current. The nitrogen acted as a carrier gas for the sample which, by means of the attached gas chromatograph, contained the separated traces of the volatile substance to be measured, in particular halogenated compounds such as the CFCs. The presence of such substances resulted in the absorption of electrons, thus reducing the flow of electrons and the current. The ECD, now widely used, is extraordinarily sensitive and can measure the quantities of a volatile substance even to as low as one part per trillion (Bunyard PP.,2022).

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

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

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. The contrast with the Earth's 0.03% of carbon dioxide (the 1960s), 78% nitrogen and 21% oxygen was telling. 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 (Bunyard PP..2022).

Moreover, 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°C compared to the actual 15°C of today's Earth.

But, how could life have a role in controlling surface temperatures? When he was in the South Atlantic, Lovelock noticed the ubiquitous presence of the volatile substance dimethyl sulphide (DMS). Together with Robert Charlson, Meinrat Andreae and Stephen Warren, he developed what became known as the CLAW Hypothesis using the surname initials of its proponents. The essence of the theory involved the release of DMS by phytoplankton such as the coccolithophores which are single-celled photosynthesising algae with a calcified shell. The DMS is rapidly oxidised to sulphur dioxide, sulphuric acid or methane sulphonic acid, with any one of such compounds acting as cloud-condensation nuclei. The coccolithophore metabolism and therefore the growth of the algal bloom are best served by warmer oceanic temperatures. So, right here, we have negative feedback in the sense that the surface sea temperature depends on how clear the skies are and the more DMS that is emitted, the cloudier the skies become and the cooler the surface waters beneath.

For their growth the coccolithophores need upwellings of nutrients, the rate of upwelling in turn depends on the surface temperature. Warm surface temperatures generate a thermocline layer which is impenetrable to nutrients coming from below. For that reason, the coccolithophores do best when surface temperatures are no higher than 8°C. Above 12°C, a thermocline layer forms, impeding the growth of phytoplankton. Thus, warmer sea temperatures are likely to leave the surface waters barren. Consequently, the negative feedback relationship at lower temperatures, when the sea surface is turbulent and mixing, *becomes a positive one* as the sea-surface temperatures rise above a critical point. The net result is a lack of cloud-forming nuclei. (Charlson, R. J., Lovelock, J. E., Andreae, M. O. and Warren, S. G. 1987).



Fig. 32. Self-limiting negative-feedback loop between phytoplankton, temperature and clouds contrasting with a positive-feedback when the surface water temperature exceeds 12°C – Image by Peter Bunyard.



Fig. 33. Images of coccolithophore blooms and the amazing design of their skeletons – Peter Bunyard

In conclusion, we are extremely fortunate that Lovelock was invited to join NASA in devising experiments and technologies to test for life on Mars because it induced him to reflect on the extraordinary phenomenon of life on Earth and how it came to be that life had persisted for close to 4,000 million years, even surviving a number of extinction events. His contribution to our understanding of the processes underpinning the success of life in transforming the Earth, such that it can host the panoply of nature, must surely place him amongst the great scientists of the world. For those who listened to him and studied his revolutionary ideas, including the science behind them, Lovelock fundamentally changed their outlook on what should be humanity's responsibility towards nature. He made it clear that the climate of the Earth is not just a consequence of physical forces beyond our control, such as the Milankovitch wobbles as the Earth orbits the Sun, but that it is transformed by biotic physiology and metabolism (Bunyard PP., 2022). Evidence for this is provided by phenomena such as seasonal changes to greenhouse gases, and the changes to albedo as vegetation deciduously sheds leaves. The climate, indeed, the atmosphere, are carefully calibrated products of the biosphere shaping the conditions for life to thrive in its interaction with the high-powered energy from the sun and the freezing cold of the universe, both of which by themselves make the existence of life near impossible.

## **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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# The Magic of Life, Photosynthesis and our Future

# 4.1 THE PHYSICS OF LIFE

Living organisms, with their ability to maintain and increase order within their structures, reverse entropy. Through metabolic processes, energy is harnessed and utilised to fuel the maintenance, growth, and reproduction of living systems. Cells, for instance, constantly engage in molecular and biochemical reactions that maintain their organisation and functionality.

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 a 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<sup>-7</sup> to 10<sup>-8</sup> 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, uncouple it from its partner, and let it drop back to the ground state through its biological machinery utilising its excess energy for life processes.

This process is magnificently efficient, although the net result is determined by other factors as well, such as the availability of water, essential nutrients, carbon dioxide levels, how much oxygen is present, whether clouds are obscuring the sun, what season it is, and what the temperature is. The net result is that of 240W/m<sup>2</sup> received at the Earth's surface barely 0.7W/m<sup>2</sup> 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.

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.

Approximately one-third of the Earth's energy is absorbed by the hydrological cycle, while another third drives the convective forces responsible for moving air masses that carry the moisture essential for watering the land. At each step of this intricate process, energy is seemingly "lost," although we must not perceive it as such, as this energy fuels the very dynamics that have shaped our planet.

The extraordinary efficiency displayed in living organisms distinguishes them from man-made machines.

While this story may seem complex, the central message is this: we are part of a living organism, called Earth. The brilliantly designed architecture and metabolism, tweaked over hundreds of millions of years of evolution have 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 recognise 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.

In the first part of the book, we want to take a much deeper dive into the intricacies of how the climate works as a function of this living organism called Earth of which we are a part. This is not an academic exercise because it is the foundation for the second part of the book where we propose radical action to reverse the damage we have inflicted on our Planet, which is now starting to spiral down into a situation best described as multi-organ failure. Make no mistake, the current scientific warnings about the climate are serious underestimations of the danger we are in. Collapse can come fast and furious.

The goal of this book is to offer a path out of the climate chaos we are in and with that tackle a whole series of connected problems that are already overwhelming many societies and will soon overwhelm all globally interconnected complex human societies unless we start the great work of our time which is restoring the planet to its former health and vigour and with that shape the conditions for all humans to thrive in sync with nature and graced with the dazzling beauty and abundance of the myriad of species that surround us. Like our next of kin, they give deep meaning to our lives and we are all related. When we succeed in restoring the planet's health, we will simultaneously take on the challenges of food and water security, extreme poverty, and excessive wealth. Equity is not just a human value to be pursued, it belongs to the internal logic of a well-functioning, healthy organism, such as our planet. Together we will be able to restore lands, increase their degraded fertility, and increase the well-being of communities, especially in the Global South. Should some politicians from the Global North read this page, then listen up! If you want to protect our flagging democracies, embrace the recommendations in this book, for they will slow, stop, and reverse the migrations of the millions that no longer find a way to live in their areas. Let us grant them the tools and finance to regenerate their degraded landscapes and communities and with that calm the weather and cool our planet to avert the collapse of all our societies. A lot of the damage caused to the planet has been by the voracious and parasitical excursions of the people in the Global North to confiscate and impound wealth from other regions. Whether it is colonialism or capitalism, these systems have dangerously degraded the living organism we are part of. It is high time to reverse the damage for the sake of the young and those who still want to be born.

## **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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# **Climate Chaos Will Curse your 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, and long-lasting droughts are not only more severe than half a century ago but have become far more frequent.

Scientists from all over the world have now gathered sufficient unequivocal evidence to show that recent climate change, as evidenced by an overall warming of the surface of the Earth during the last few decades and which includes an increasing number and intensity of extreme events, is primarily the result of our industrialised way of life, including our systems of transportation, the industrialisation of agriculture, our destruction of rainforests, particularly in the tropics, our living increasingly in megacities, with populations running into the millions, and, not least, our dependence on energy from coal, petroleum and natural gas – the so-called fossil fuels because they were formed from once-living plant matter some 300 hundred million years ago, during the period known as the *Carboniferous*.

Dr. James Hansen, a climatologist who worked for NASA – the National Aeronautics and Space Administration of the United States – at the Goddard Space Institute in New York, is deeply concerned about what might be the consequences to the Earth's were temperatures to rise by 2°C (Celsius) before the end of the century. He believes we can avoid such temperature rise only if we reduce the concentrations of greenhouse gases in the atmosphere to 350 parts per million (ppm by volume), while currently, we have exceeded 420 ppm, which is some 50 percent higher than the concentrations of pre-industrial times, some 200 years ago.

During the *Carboniferous* period of some 300 million years ago, carbon dioxide levels dropped dramatically in the atmosphere, as the gas was transformed into buried organic matter while, simultaneously, oxygen levels rose to as high as 35 per cent, compared with the 21 percent of oxygen today. Since carbon dioxide is

a greenhouse gas, which holds heat back at the Earth's surface – in the form of infrared radiation - in comparison to oxygen which is not a greenhouse gas, the production of oxygen, at the expense of carbon dioxide, would have caused the Earth's surface to cool and allow the formation of glaciers and polar ice. That glaciation, by killing the pre-gymnosperm trees of that era, helped form the coal seams which have become the main feature of the carboniferous era. And shallow seas, penetrating the landmass of Pangea, with their rich, diverse, calcareous creatures, were the sites where limestone deposits formed. Together, the carbonisation of the forests and the deposition of calcium carbonate would have significantly reduced the concentrations of CO<sub>2</sub> in the atmosphere. That fact alone tells us how much the concentration of greenhouse gases in the atmosphere depends on the activities of living organisms at any one moment in time. In time that cooling would have balanced out because of massive forest fires brought on by the high levels of oxygen, which would have caused damp forests and vegetation to burn if set off by lightning or a spark from a nearby volcano, with the net result that carbon dioxide concentrations would again have begun to rise, adding to the greenhouse effect and generating the balance of gases in the atmosphere to the kind of levels we find today.



Fig. 34. Increasing atmospheric CO2 content over time – Courtesy NOAA

# 5.1 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 seawater, especially in the wake of powerful storms.

The concern that sea-level rise will cause islands to flood and so have to be abandoned was made graphically clear by the prime minister and his cabinet of ministers of the Maldives in the Indian Ocean. In October 2009, they held a symbolic cabinet meeting underwater, off the shore of the Maldives, with the ministers using scuba-diving masks to enable them to breathe. It may have seemed a crazy gimmick, but the idea was to remind the governments of other countries that they must do all in their power to agree to a significant reduction in emissions of greenhouse gases before what was to be the forthcoming climate meeting in Copenhagen, Denmark, in December 2009; otherwise, islands such as the Maldives might well be doomed before the century is out.

Nor is that idle speculation on behalf of climatologists; in 2005 some 500,000 people from the island of Bhola in Bangladesh had to abandon their homes because the rising sea level brought about by the expansion of the surface waters from global warming had flooded more than half the land area.

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.



Bangladesh and the greatest delta in the world. Millions of people in the region are threatened with catastrophe because of sealevel rise. A rise of one metre over this century would spell unmitigated disaster.

Satellite image courtesy of NASA.

#### Fig. 35. Satellite image of the largest river delta in the world in India and Banglesh – courtesy NASA

It will not just be the fear of drowning that will drive people away, but the failure of their crops because of the intrusion of salt water into the soil and fresh drinking water. Again, in Bangladesh, as many as 20 million people are at risk on account of rising sea levels.

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 21<sup>st</sup> century. Where will all those people go once they can no longer 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?

Since it is we human beings, with our growing population and needs, who are in all probability upsetting the balance and causing dangerous climate change, it is up to us to do something about it. But what? One way is to try and reduce our impact on the environment, by cutting back substantially on our use of fossil fuels with the purpose of reducing the emissions of greenhouse gases, while still attempting to maintain or, in the case of developing countries, to achieve a comfortable consumer lifestyle; another way is to adapt, for instance, by building ramparts and dykes to keep the sea out; a third way is to try and offset the global warming now taking place by what is called *geo-engineering*, for example, by erecting enormous mirrors in space so as to reflect sunlight away from the Earth, in the hope of keeping the surface cooler.

Were we collectively to cut back on our consumption of fossil fuels, what would we replace them? Do we have to find an exact equivalent in energy terms to substitute for our growing energy needs, watt for watt so to speak? Or can we reduce our energy demands by improving energy efficiency all the way from production to enduse - that point in the home, factory, vehicle, or public building, where we actually switch on our appliances? And what about forms of energy production, that emit far less greenhouse gases per unit of energy consumed and which are renewable, such as wind turbines, wave machines, photovoltaic devices, solar thermal plants, the growing of special energy crops, like sugar cane, or African palm, geothermal plants, like those currently used in New Zealand and Iceland, and tidal barrages, like the mega one proposed for the Severn Estuary in England? Will they add up to providing us with an adequate and sufficient substitute for fossil fuels? While all those technologies are either in use or being developed, it must be remembered that fundamental limits exist as to how much we can tap. The Sun is not just there to power our machines but actually generates the movement of oceans, the formation of clouds which bring rain, the movement of the air mass, such that we have winds, allows plants to grow through photosynthesis, keep us warm and gives the Earth its seasons such that it does not freeze over.

It may be that the only way we can properly substitute for fossil fuels is through international cooperation on a scale never seen before, such as the construction of a direct current super electricity grid that can efficiently and conveniently bring energy into our homes and workplace from thousands of kilometres away, indeed from different countries in the world, some blessed with clear skies and direct sunlight, such as North Africa, others with an excellent wind regime such as the United Kingdom, others with large tidal ebbs and flows, such as Fundy Bay in Newfoundland.

The concern is that global warming will cause more violent extremes of weather than those which we currently experience and which can be absolutely devastating, as happened with the horrendous mudslides in Venezuela in mid-December 1999, when over two days, Caracas and the neighbouring region received the rain it would normally get in an entire year. Then some 23,000 people lost their lives and 150,000 lost their homes. Late in September 2009, the Philippines too suffered unprecedented floods which left as much as 80 per cent of the Capital City, Manila, under 2 metres of water and caused hundreds of thousands to have to flee from their homes. Meanwhile, Hurricane Katrina, designated as category 5, which struck the Louisiana coast in August 2005, and devastated the city of New Orleans, gives us some idea of the power of single extreme weather events to change the course of history. Many failed to escape the city in time or decided to stick it out, and more than a thousand died. Twelve years later, in 2017, Hurricane Harvey, a category 4 hurricane, made landfall in Houston, Texas, and caused damage exceeding \$125 billion.

Climate policy has been an unwieldy beast. In the USA, under George Bush's tenure as president, the U.S. administration was sceptical of human contributions to climate change, attributing potential changes to natural climate variability. This scepticism led to the U.S. withdrawing from the Kyoto Protocol, an international agreement aiming to reduce greenhouse gas emissions by 5% below 1990 levels by 2012.

In contrast, President Obama acknowledged the reality of human-induced climate change, notably due to the surge in greenhouse gas emissions since the Industrial Revolution. His administration's recognition of this issue was marked by a pivotal agreement with Ban Ki-moon, the then Secretary-General of the United Nations, at the G8 summit in Italy in 2009. They concurred on the necessity for global action to limit the rise in global surface temperatures to no more than 2°C over the century, calling for an 80% reduction in greenhouse gas emissions by 2050. This objective underscored the challenge of balancing the energy demands of both developed and developing countries with the need for sustainable development and minimal greenhouse gas emissions. Based on what we see happening, the feasibility of reducing greenhouse gases, while resource consumption levels globally remain high, is very unlikely. The year 2023 saw a record increase of 5 ppm of  $CO_2$  emitted into the atmosphere.

A key moment in to fight against climate change came with the Paris Climate Accord, formally known as the Paris Agreement. It was adopted on December 12, 2015, by 196 parties at the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris, France. It marked a historic turning point in global efforts to combat climate change, with the central aim of keeping the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5°C, a value we are now beginning to exceed. The agreement requires all participating countries to submit nationally determined contributions (NDCs) and to pursue domestic measures aimed at achieving their targets, with the intent of increasing ambition over time. Furthermore, it established mechanisms for financial, technical, and capacity-building support to help developing countries adapt to climate change and transition to clean energy.

The adoption of the Paris Agreement has had profound consequences for global climate policy and action. It has galvanized international momentum, with countries, cities, businesses, and civil society groups taking unprecedented steps to reduce greenhouse gas emissions and invest in renewable energy and sustainable practices. The accord has also spurred innovations in climate finance and the development of low-carbon technologies. But all of this has not resulted in less emissions of CO<sub>2</sub>. On the contrary, in 2023 we saw record temperatures and a sudden acceleration of ocean surface temperatures in several parts of the world. Indeed, the challenges have only become greater, including disparities in the capacities and contributions of developed and developing countries, the need for increased financial support for climate adaptation and mitigation, and the urgency of enhancing the ability of Newly Developing Countries (NDCs) to meet the accord's temperature goals. Despite these hurdles, the Paris Agreement remains a cornerstone of international efforts to address climate change, reflecting a collective commitment to a sustainable, low-carbon future. But as we shall see, that is leaving out half of the story on climate change: carbon emissions heat up the atmosphere, but water, in its interactions with the biosphere and the atmosphere actually functions as a cooling device.

#### Climate change, global warming and the impacts on Colombia:



# Fig. 36. Paramos in the high Andes, the sponges that soak up Amazonian rains - Photo Carolina Figueroa

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 throughout 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. In fact, Colombia has every imaginable ecosystem, from the coral reefs of the islands such as San Andres and Providencia in the Caribbean, the deserts of La Guajira along the coastline between Colombia and Venezuela, the cloud forests of the Andes, the wettest tropical forests in the world in the Chocó aligned along the Pacific coast; the swamps (Cienegas) of the north; and not least an extraordinary portion of the Amazon, with its rivers, indigenous communities and spectacular remnants of the Guiana Shield, which is severed apart by the Caquetá River at Araracuara.

Some 500 years ago, before the arrival of the Spanish conquistadores, Colombia was a country supremely well provided for with water resources, whether on account of the extensive high Andean glaciers, the Cienaga swamp regions in the northern part, and the upper moorlands, the páramos, which soaked up rain that had arrived with the prevailing winds over the Amazon Basin. Still today, the climate of Bogotá in terms of rainfall is very much an Amazonian one and more than half the rainfall of Colombia is derived from that same source. How important for Colombia is that the hydrological, and climate system of Amazonia remains intact. Consequently, we must look very carefully at the threats to the Amazon's climate brought about through climate change and in particular global warming.

Today, Colombia is threatened as never before with water shortages on an everspreading scale, and it must be remembered that water is used in irrigation, especially in the Cauca, Magdalena and Tolima Valleys and for electricity generation, quite aside from the intensive use of water in the industrial and domestic sector. Gravity irrigation systems are used for the most part to water some 900,000 hectares and the efficiency of use is low with the result that Colombia is suffering from salts brought up from the subsoil and left as crystals on the soil surface. The high use of fertilisers and pesticides is contaminating water courses and having a deleterious impact on the environment.

In general, climate change and global warming threaten to cause:

- 1. A rise in surface temperature across Colombia;
- 2. Rapid and unexpected loss of glaciers;
- 3. Degradation of the páramos, with loss of ability to retain water;
- 4. Sea level rise, thereby threatening the coastal region and islands such as San Andrés;
- 5. Changes in the pattern of precipitation;
- 6. Loss of CO<sub>2</sub> from soils and biomass;
- 7. Soil degradation and erosion (Valle de Cauca);

- 8. Dramatic decline in the rains derived from the Amazon Basin;
- 9. Severe impacts on agriculture;
- 10. Increase in tropical diseases such as malaria, dengue and yellow fever:
- 11. Serious, irreversible loss in biodiversity;
- 12. Thousands of environmental refugees each year from a deteriorating environment.

Laguna de la Cocha in the High Putumayo (9,500 ft), The lake is fed by the air circulation over the Amazon. It then drains back into the Amazon, completing the cycle



#### Fig. 37. Lake de La Cocha in Colombia and huge moisture clouds overhead, carried in by the Walker Circulation from the Amazon Basin - Photo Peter Bunyard

Glaciers all over the Andes mountains have melted considerably. For example, the Colombian Sierra Nevada Santa Marta lost more than half of its glacier surface compared to 1990 when it had about 10 km<sup>2</sup>. In 2022, just 5.3 km<sup>2</sup> are 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 19<sup>th</sup> century. Furthermore, in the last 50 years, it is estimated that they have lost 3 to 5% of their glacier area per year.

Glacier melt is widespread across the globe, in Latin America, North America, Asia and Africa with enormous consequences for drinking 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 due 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, which includes the Tibetan Plateau and surrounding areas, 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. It plays a crucial ecological role as well as supporting about 2 billion people with water resources. These rivers are vital for drinking water, agriculture, and hydropower in several countries across Asia, including China, India, Thailand and Vietnam. The melting of these glaciers would be an unimaginable catastrophe.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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## 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 trade winds 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 myriad 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.

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, but leaving coral reefs bleached of algae and dying. The loss of the reefs, and the loss of mangrove swamps, all led to the coastline becoming ever more vulnerable to sea level rise and storm surges.



#### Fig. 38. Manaus, Amazonas, Brazil 09.29.23 View of what's left of the river at Marina do David in Manaus – Photo Jesper Sohof/Shutterstock.

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? The answer is we do not know, not precisely. However, as we are being made increasingly aware, 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.

Already, from Tocantins right up to Guyana, we are seeing the Amazon Basin drying out and forming a 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; and that the forests are no longer able to sustain themselves. Without the forests, all the countries in South America would suffer dramatic changes to their climate and rainfall. In essence, it would be catastrophic, and 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 Brazil, large areas have been cleared in order to plant soybeans, particularly in the State of Mato Grosso which flanks the State of Amazonas. Subsistence farmers, too often have little idea how to farm in the heart of the tropics, where soils are often fragile and depleted of nutrients. For lack of opportunity, such colonists may be forced to occupy the least fertile areas, where their actions rapidly deplete the soil. The net result is a cancer-like need to clear more forest, just for subsistence.

Governments and corporations tend to blame rainforest destruction on the actions of subsistence farmers and settlers. However, in countries such as Brazil and Indonesia, government schemes have deliberately encouraged the 'colonisation' of rainforests and, throughout the Tropics, small-scale farmers have been forced off their own lands and into poorer forest areas by large agricultural companies, as during the 1970s and 80s when small-scale tenant farmers had to leave the rich fertile lands of Rio Grande do Sul in the southern part of Brazil. In point of fact, in Latin America and no less in the Brazilian Amazon, extensive cattle ranching has become the major cause of deforestation, both in bringing about primary deforestation and in taking over land which had been colonized, but because of a rapid decline in soil fertility and hence production, had been abandoned or in reality sold on.

#### 6.1 AMAZON DESTRUCTION

Going back at least 50 years, Brazil has unleashed a process of development in its Amazon Basin that is leaving vast areas shorn of trees. A combination of satellite imagery and verification on the ground suggests that, by 1998, the area of forest cleared in the Brazilian Amazon had reached some 549,000 square kilometres, hence about the size of France out of a total area as large as Western Europe. In the ten years since, another 150,000 square kilometres have gone, with 24,000 square kilometres alone being destroyed in 2004 – an area larger than Belgium. In 2004, remote satellite sensing picked up more than 35,000 separate fires in the Brazilian Amazon and the situation was only marginally better in 2005. Meanwhile, because of government intervention in controlling deforestation and in no small measure because of the downturn in global economy, the year between 2008 and 2009 saw the annual deforestation fall to some 8,000 square kilometres.

In no more than a few decades, Brazil has managed to deforest an area far greater than that lost over the preceding five centuries of European colonization.



Fig. 39. Huge Soy Bean plantation after original vegetation was removed. -Photo Marcus Mesquita /Shutterstock



Fig. 40. Satellite data collected by Brazil's National Institute for Space Research (INPE) from August 22, 2019. Around 75,000 fires across the Amazon since the start of that year – Courtesy NASA Worldview

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 about what will happen to the climate if we insist on cutting down great swathes of trees.

Certainly, what happened in 2005 and 2023 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 gone beyond them.

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 focus 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 to crash.



Fig. 41. Graph showing the relation 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

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

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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.



Fig. 42. Relation between size of clearing and precipitation – Graph Courtesy Dr Werth and Dr Avissar

#### 6.2 DEFORESTATION AND FIRES

Thunderstorms and lightning strikes have been blamed for starting fires. Yet, according to Mark Cochrane of Michigan State University and Daniel Nepstad, of the Woods Hole Oceanographic Institute, the chances of fires taking hold in the natural forest as a result of lightning are minimal. Fires in the Amazon are a consequence of deforestation and land-use change. Indeed, Nepstad and his colleagues find that forests that have been subjected at least once to fires are far more vulnerable to successive fires in terms of tree mortality.

Initial fires may cause up to 45 per cent mortality in trees over 20 dbh (diameter breast height) and subsequent fires up to 98 per cent mortality. Meanwhile, during observations of fires in December 1997 fires in the eastern part of the Amazon, in Tailândia, they found that initial fires led to the immediate release of 15 tonnes of carbon per hectare and recurrent burns, up to 140 tonnes of carbon per hectare. Charcoal studies indicate that in lowland tropical rainforests natural fires are rare events, perhaps involving a rotation of hundreds if not thousands of years. According to recent research by Cochrane and Laurance, "Fire-return intervals of less than 90 years can eliminate rain forest tree species, whereas intervals of less than 20 years may eradicate trees entirely. Fragmented forests in the eastern

Amazon are currently experiencing fire rotations of between 7 and 14 years. Previously burned forests are even more prone to burning, with calculated fire rotations of less than 5 years."

Successive dry years, such as a succession of El Niño years, will also make the forest extremely vulnerable to drying out and fires. During the exceedingly strong El Niño of 1998, says Nepstad, one third of Brazil's Amazon rainforest experienced the soil drying out down to 5 metres, close to the limits of water uptake through the roots. Consequently, 3.5 million square kilometres were at risk, with some trees having to pull water up from as deep as 8 metres. During that period of stress, Nepstad noted that tree growth went down practically to zero as evidenced by canopy thinning rather than leaf-shedding.

How close are we to that critical point when the forests are no longer widespread and dense enough to sustain their humidity and that of the surrounding air? It may be that we are perilously close in some regions of the Brazilian Amazon, such as in the southwest, on the border between Brazil and Bolivia, where rainfall has recently begun to increase. To some that may indicate that deforestation is not linked to rainfall: to Roni Avissar, such increases spell potential disaster and the remaining forest may be in grave danger of collapsing on account of an impending dramatic decline in rainfall.

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 do 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 and all the way to the Andes.

This tightly coupled climate system of air currents and forest-driven evapotranspiration is far more vulnerable to deforestation than we believed 30 years ago. The work of Roni Avissar and Pedro Silva Dias and others indicates that expanding the size of a clearing for agro-industry in the Amazon Basin, at least in the southwestern part, will lead to a sharp decline in rainfall and with that the die-back of the surrounding forest. And once the process of die-back begins, like cancer, it will spread deeper and deeper into the remaining forest as a result of the sun baking down on an ever-increasing area. Consequently, day-time temperatures over the cleared areas will rise by 10°C or more compared to the forested area.

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 that 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.



Fig. 43. 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. Recycling by means of 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 ultimate result of that drying out may well be the desertification of vast areas of the central and western Amazon Basin. But first, we would expect 'savannisation' and that is precisely what appears to be happening, as Lucy Hutrya and Steven Wofsy at Harvard have recently discovered. Changes in hydrology as a result of deforestation within the Amazon Basin will have a massive impact on rainfall patterns over the tropical Andes.

Were it to be so, deforestation and soil drying out would lead to diminished rainfall over the eastern and mid part of the Andes (in Colombia the Andes divide into three distinct cordilleras) that would have a dramatic impact on the source of the large rivers, such as the Caquetá and Putumayo, that flow into the Amazon River, as well as rivers such as the Magdalena and Orinoco which are also fed by the Amazonian air mass circulation, but which flow respectively to the Caribbean and to the Atlantic via Venezuela. It would also affect available water for drinking, for agriculture and for maintaining large cities such as Bogotá. Meanwhile, world-granary countries such as the United States are threatened on both counts. First, when the Amazon self-destructs through being sucked dry by agro-industry.

Second, the accumulating impact of greenhouse gases in the atmosphere may lead within a few decades to a sudden switch in air mass movements over the Pacific and the Americas. Those El Niño-like changes will combine with the impact of massive agro-industrial clearings to the point when the humid rainforests of the Amazon can no longer sustain themselves and the teleconnections to the Midwest of the United States will fail.

The healthy forest accumulates carbon from the atmosphere in the form of organic material and biomass. According to John Grace, of Edinburgh University and others, who have been contributing to the Large-scale Biosphere-Atmosphere Programme (LBA) in Brazil, the average uptake of carbon dioxide over the Amazon Basin in non-El Niño years may be as much as 0.56 GtC per year (GtC =  $10^9$  tonnes of carbon per year), hence equivalent to 8 per cent of total annual emissions from all human activities. Just on their carbon uptake alone, says Grace, such rainforests are providing an irreplaceable global environment service.

#### 6.3 CARBON RELEASES

The downside is the release of carbon from deforestation. Philip Fearnside of Brazil's Amazon Research Institute in Manaus estimates such carbon emissions as 'net committed emissions', which take into account both decay following a fire and any future reabsorption of carbon by the new landscape. During the 1980s the average annual net committed emissions from land-use change in Brazil was 0.556 billion tonnes of carbon; hence about one-eleventh of the 6.4 GtC emissions from fossil fuel burning across the planet and just under one-quarter of the total 2.4 GtC emissions from the tropics.

Unverified statements that whatever vegetation replaces the forest, such as pasture, it will, over time, regain all the carbon that has been lost, have proved little but wishful thinking: field research indicates that 7 per cent at most of the original carbon gets reabsorbed over time by the replacement landscape. Another mistake is to ignore the carbon release from the decomposition and decay of the remaining biomass after the initial burn. According to Fearnside, the final tally of carbon emitted from burning felled trees is likely to be at least three times greater than measured at the time of the fire. As a result, the emissions in any one year may be augmented by emissions from deforestation that took place in a previous year.

Were all the remaining Brazilian Amazon forests to be lost, then, according to Fearnside, the potential net committed emissions would amount to as much as 77

GtC, a quantity that conforms to the predictions of Richard Betts and others at the UK Met Office. That amount, Fearnside points out, would be 10 per cent higher than the 70 GtC that could be gained from full implementation of the Kyoto Protocol together with a 1 per cent compounded reduction per year in the emissions of the countries (developed) from fossil fuel burning between 2010 and 2100.

#### 6.4 THE AMAZON AS EVAPORATIVE FORCE AND HEAT PUMP

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 a 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<sup>th</sup> 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. For that, they needed to refer to plant physiology and they took into account the recycling of rain through evapotranspiration, which over a long stretch, like the 7 million square kilometre Amazon Basin, is the mechanism by which the rainforest in the centre and further extremities inland can receive adequate watering.

The Hadley Centre model (HadSM3 coupled to a dynamic global vegetation model –TRIFFID) predicts impacts on surface temperature, on ocean currents, and ultimately on the state of the Amazon rainforests as a result of 'business-as-usual' emissions of greenhouse gases, mainly CO<sub>2</sub>. Hence, the models predicted that global surface terrestrial temperatures would rise by a good 50 per cent more than indicated in the various IPCC assessment reports, perhaps to as high as 9°C, and that, consequently, El Niño-like changes would take place in the Pacific Ocean. The result would be that the trade winds would falter and the rain-bearing Hadley Cell Circulation over the tropical Atlantic would diminish sufficiently to bring about large-scale forest dieback over the entire Amazon Basin.

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).

Meanwhile, the trade winds have picked up masses of water vapour, more than 12 million (10<sup>12</sup>) cubic metres (tonnes) worth. When that same air mass, passing over the Basin, reaches the Andes in the far west of South America, it is forced upwards because of the topography. It loses its water vapour, all the while releasing its latent heat, and this helps push the air mass up still further. The next stage is the movement of the air mass in the direction of North Africa, helped on by the Coriolis force which spins the Earth counter–clockwise, completing the circulation of the Hadley Cell. The circulation is thus seen as primarily generated through the thermodynamics of the system.

The rationale is that were it not for the Walker and Hadley circulations taking a humid column of air up towards the higher latitudes, temperatures over the Equator would soar during the daytime and plummet at night. The transport of water in the atmosphere from the Amazon Basin is of considerable climatic significance in the transfer of the sun's energy; dry air is not only a poor conductor of heat, but it carries far less energy in a given volume compared to water vapour. The condensation of enough vapour to fall in one day as 2 cm of rain is sufficient to warm the entire tropospheric column by as much as 6°C, whereas sunshine over that same column of air would at best heat it up by 2°C, most of which would then be lost through radiative cooling.

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 based on 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 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 freshwater resources in countries such as Colombia, Peru and Ecuador, let alone in Brazil.

How do they come to that uncompromising view? The answer lies in their review of hydrological processes and whether they take place over forested regions of the world, or ones, which for whatever reason, have lost their forests. From the basic physics of the partial pressure gradient, Makarieva, and Gorshkov find that the

high leaf area index of the closed canopy rainforest is vital to the process of generating a horizontal pressure gradient – in the case of the Amazon, from the tropical Atlantic inland over the forest - and that the replacement with pasture or a plantation of soya, in which evapotranspiration is an order of magnitude lower, simply will not provide sufficient water vapour to the lower atmosphere to provide the necessary pressure gradient. Without the forest, the gradient will go the other way, from the continent to the ocean, hence adding to the drying out.

Meanwhile, the process of evapotranspiration, as sustained by the closed canopy rainforest, is a powerful mechanism for the transference of energy in the form of latent heat, acting like sweat both to cool the vegetation and to provide the near-saturation of the lower air column with water vapour such that rain clouds form further inland, helped in no small measure by the release of cloud condensation nuclei from the same stomata. In equatorial regions, such as encompassed by the Amazon Basin, where solar radiation is more than double that throughout the year of the higher latitudes, evapotranspiration from native forest, with its closed canopy and sub-storey vegetation, will consume as much as 50 per cent of the incoming radiation. Indeed, without the natural vegetation, the Sun's energy will take the form of sensible heat, which will not only reduce the potential of rain forming from evapotranspiration but will lead to the baking and compaction of soils and even to its laterization, in which minerals like iron become oxidized and form a hard, impenetrable pan.

Basically, the biotic pump, as proposed by Makarieva and Gorshkov, functions as a result of marked changes in the partial pressure exerted by water vapour at different altitudes in the air column above the rainforest. Just above the canopy, warm temperatures permit the air to hold large quantities of water vapour, and so the partial pressure is high. That partial pressure, plus the higher temperature of air close to the ground act together to create the process of convection by which the air is thrust upwards. As it does so, and gains height, further expansion takes place because of reduced pressure, thereby causing a loss of heat and a simultaneous drop in temperature, just as happens in the expansion chamber of the cooling circuit of a fridge. At the same time, low temperatures high up in the air column cause a sharp reduction in the saturation pressure of water, such that the water vapour condenses and forms droplets of rain.

The loss in temperature because of the air mass expanding as it moves upwards is compensated to some extent by the release of latent heat from condensation, but even though the conversion of latent heat to sensible heat may delay total condensation that in itself does not alter the fact that the conversion of water vapour to water brings about a significant drop in partial pressure and, as a consequence, aids the upward movement of water saturated air from below such that it pushes upwards, like a piston driven upwards by the exploding fuel in an internal combustion engine.

"In the presence of a large vertical temperature gradient," say the Russians, the vertical distribution of saturated partial pressure,  $pH_2O$ , departs significantly from the static equilibrium; at any height,  $pH_2O$  is over five times larger than the weight



of the water vapour column above this height. For this reason, practically all the water vapour ascending in the atmosphere undergoes condensation."

#### Fig. 44. Over regions with closed-canopy forests, precipitation levels remain high, whereas, to the contrary, deforested regions show an exponential reduction in rainfall as one passes from the coast to the interior – Graph courtesy Anastassia Makarieva and Victor Gorshkov

The air at the base of the air column is then replaced by air moving in horizontally, which, according to Russian physicists, derives from the ocean. This process of convection, powered by the partial pressure of water vapour from evapotranspiration, therefore sucks in the Trade Winds, which have accumulated significant quantities of water vapour as they pass over the Tropical Atlantic Ocean between Africa and Brazil. That is a very different notion indeed, from that commonly believed whereby the trade winds are considered to drive the air mass circulation system over the Basin, rather than being sucked in.

If, as indeed happens, the air above the tropical ocean is also drawing up water vapour, how then can the forest evapotranspiration pull in air from the ocean? Here, the physicists explain, the multiple layers of surface provided by the leaves of the natural forest provide more water vapour per square centimetre than does the ocean and so a differential pressure will exist between the two, acting along the horizontal plane. Add into the equation the capillary action that takes place in the xylem and which draws water into the stomata, from where it evaporates, and also that chemical compounds and maybe bacteria too act as cloud condensation nuclei (CCNs) when released from the stomata, and we have an evaporative force that is finely tuned for generating rain and which simultaneously brings about significant partial pressure differences in both the vertical and horizontal plane, so causing a dynamic disequilibrium and therefore the mass movement of the air.

Wonderful to relate, the natural forest keeps the system going during the dry season and even during drought years, as during a strong El Niño, by increasing leaf coverage and hence the leaf area index by as much as 25 per cent compared

with the wet season. Indeed, as Myneni and his colleagues, at Boston University, have shown from satellite images, the forest appears to anticipate the dry season with the growth in leaf area taking place before the 'summer' months have actually taken hold. The increase in leaf area means essentially that the root system of the forest must draw up more water, and it is now known that the tap roots, taking water from the water table, also pass water through lateral roots such that it dampens the area around each tree and keeps soil moisture high. The increase in evapotranspiration and the resulting convection draws in humid air brought in by the Trade Winds from the tropical Atlantic in the other hemisphere.

That extraordinary process whereby the rainforest manages its own climate would seem to reinforce the notion of the biotic pump and the evaporative force as described in physical terms by Makarieva and Gorshkov, and they point out that the rates of evaporation and precipitation in tropical rainforests are even an order of magnitude higher as those of evaporation and precipitation over open oceanic surfaces at similar latitudes. Nor, is such biotic regulation of the water cycle limited to the tropics, and again the physics shows that undisturbed temperate and boreal forests will generate an evaporative force, albeit far weaker than in the tropics, during the late spring and summer months, which will generate a partial pressure gradient from the ocean to the land, again taking a similar latitude into account. That biotic pump is nonetheless switched off in winter.

The upward motion of expanding and cooling moist air sustains the continuous process of condensation and does not allow the hydrostatic equilibrium of air as a whole to set in. The motion continues as long as there is water vapour in the rising air to sustain condensation.

"That physical view", say Makarieva and Gorshkov, "is in direct conflict with the traditional paradigm which considers differential heating to be the major driver of atmospheric circulation. However, this consideration critically fails in the case of the strongest winds observed on Earth, the hurricanes, that, as is well-known, develop along nearly isothermal surfaces. But if differential heating is not necessary for producing the strongest winds, perhaps it is not indispensable for producing moderate and weak winds either. The evaporative force concept that relates wind velocities to spatial differences in the intensity of condensation rather than heating provides a unifying explanation for both hurricanes and tornadoes as well as for stationary circulation patterns. On a related note, according to the traditional paradigm, the regions of air ascent should be associated with positive buoyancy. In contrast, observations of atmospheric updrafts indicate a wide range of positive and negative buoyancies. The evaporative force concept resolves the puzzle. Air pressure depends on two independent variables, temperature and the number of air molecules in a unit volume. Consequently, there are two independent ways of making local air pressure higher than that in the neighbouring area, so as to initiate air motion: (1) to warm the air locally (this is what the traditional paradigm of horizontal differential heating is about) and (2) to reduce the number of air molecules in the neighbouring area (this is what condensation is doing in the vertical dimension). Thus, if the condensation is intense, it can make even dense

cold air rise from the surface by creating a strong weight imbalance in the upper part of the air column."

The logic of the evaporative force, as described in Makarieva and Gorshkov's theoretical analysis, 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 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. The western reaches of the Amazon, as well as the foothills of the Andes, could find themselves receiving less than one per cent of the rainfall they currently experience; they could become as dry as the Negev desert of Israel.



Fig. 45. Precipitation recycling is faltering much faster than conventional models predict without reckoning with the Biotic Pump phenomenon. The Amazon will turn into a desert very fast – if it dies back! Courtesy Anastassia Makarieva and Victor Gorshkov. – Graphic Peter Bunyard Perhaps, the extraordinary drought year of 2023 for the Amazon Basin, which particularly affected the southwestern region, has given us a foretaste of what would happen were the forests to go. During that year, the tropical waters off Brazil and up into the Caribbean were a degree or two warmer than normal, with a corresponding increase in the oceanic evaporative force. That increase may have tipped the balance, at least for that year, given the degree of deforestation in the southeastern and southwestern regions of the Basin, such as altering the air mass movement over the Basin and drawing it more towards the ocean rather than following its normal trajectory over the Amazon.

"Despite the general meteorological wisdom that warmer air is lighter and hence rises, so it is an area of low surface pressure (which presumes wind flow from the ocean to Sahara and from the Amazon and Congo to the ocean), in reality, the prevailing winds blow in the opposite direction in all the three regions. This is perfectly explained by the biotic pump," declare Makarieva and Gorshkov, "and not by differential heating. In fact, it is the condensation gradient which explains the direction of the winds, whether from the ocean to the continent or vice versa."

Empirical evidence for the Russians' articulation of a biotic pump comes from their unique study of the relationship between the precipitation pattern over river basins in which they show substantial differences according to whether or not the region through which the rivers pass is forested. The Mississippi River Basin is a case in point: where the land is forested from the Atlantic coast inland, stretching some 1,750 kilometres, the precipitation stays steady at some 1,000 millimetres over the year; further inland, where there is no forest, the rainfall declines exponentially to little more than 200 millimetres.

Meanwhile, rainfall right across the Amazon Basin remains substantially the same at around 2,400 millimetres per year and even increases at the western extremity of the Basin, for instance in the bio-rich Colombian Amazon, to as much as 4000 millimetres.

In essence, Makarieva and Gorshkov believe that climate stability, within a limited temperature range, taking glacial and inter-glacial periods into account, has been brought about largely through the evolution of continental forests. In terms of sheer area, the boreal forests of Russia, Canada, and the tropical rainforests of South America and Central Africa, remain critical to the maintenance of a climate that retains some semblance of stability.

For the Russians, the keeping of those forests is every bit as important as concerns over greenhouse gas emissions and consequent global warming.

"Most importantly," they say, "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 amount of oceanic moisture 'brought' to the Amazon River basin by the models (the modelled atmospheric moisture convergence) proves to be two times less than the actual amount empirically estimated from the value of the Amazon runoff (Marengo, 2005). It is obvious that the traditional accounts of moisture transport in the other great river basins, including Siberian and North American rivers (Makarieva et al., 2009), will similarly have to be seriously reconsidered to incorporate the major effects of the forest moisture pumps, the anthropogenic destruction of which is currently threatening to turn the landmasses back into primordial deserts."

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.

#### Impacts of Deforestation in Amazonia:

- Strong emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O contributing to Global Warming
- Failure of biotic pump (evaporative force) and radical reduction in evapotranspiration
- Nutrient loss
- Radical reduction in energy transport (via Latent Heat)
- Increase (10°C) in soil temperature
- Collapse of hydrological cycle & drying-out plus warming of páramos
- Loss of glaciers in the Andes (decline in humidity)
- Failure (100%?) in the rains in the centre and west of the Basin
- Desertification
- Loss of teleconnections (eg. to the USA and via SALLJ to Argentina)
- Weakening of teleconnection circulation between S. America and Africa
- Increase in vector-borne diseases i.e. malaria, dengue
- Could weakening of Hadley Cell circulation and hence of Atlantic Trade Winds lead to a greater likelihood of El Niño-like years?

**Soya - the Latest Destroyer:** As new markets have opened, particularly in the Far East, and in competition with the United States, Brazil has been progressively expanding the land laid down for industrial soybean production. In 1998 Brazil produced about one-quarter of the world's soybean harvest, putting it second to the United States which produces approximately half of the global harvest. In 2024, Brazil's land under soya is expected to be 41.4 million hectares, therefore more than California or Germany's total land surface.



## Fig. 46. Complete schedule of complex interrelations between the biosphere on land and in the ocean in interaction with water and the atmosphere. The brown solid arrows are positive interactions and the blue dotted arrows are negative inverse reactions. – Graph by Peter Bunyard.

As Philip Fearnside points out, soya growing in Brazil spread initially from the states of Paraná and Rio Grande do Sul in the south, to the *Cerrado* (savanna) region in Mato Grosso. Meanwhile, all along the way, peasants have been displaced, either those in the south who were living off subsistence maize, beans and coffee, or those who had already cleared land in the *Cerrado* and parts of the Amazon, as in Rondônia. Since soya production employs only one person on the ground for every 11 subsistence farmers, the peasants have little choice either to move to the city or to move the colonisation frontier ever onwards and outwards. In 1996, for instance, Rondônia had 1800 hectares down to soya; in 2023 it is 635,000 hectares. In Maranhâo the soy area increased from 89,100 hectares to 475,000 hectares over the same period.

The ecological impact of soya production, especially in the *Cerrado* and Amazonia, is severe. The *Cerrado* has biodiversity equivalent to the rainforest, and even more so in the highly vulnerable *ecotone* region twixt forest and savanna. A major concern for environmentalists is the use of agrochemicals for industrial agriculture and soya cultivation in the *várzea* flood plain of the Amazon near to Santarém. During the dry season, the area under water shrinks, thereby concentrating the chemicals in soils and wildlife, including fish.

The advancing front of industrial soybean production is unquestionably the leading driver of all the major new transportation projects, including the creation of new highways, the channelisation of rivers for navigation, and the construction of new railroads, which will penetrate from the centre of Brazil into the very heart of the Amazon. What is therefore no less than a massive government subsidy has the intention of getting cheap soya transported by ship to Europe, and particularly to Holland for fattening pigs and milk production, and to China, again for livestock production. China, in 2005, signed an accord with Brazil to help develop the infrastructure necessary for the export of Amazon products, such as soya and timber, across the Pacific. Since then, Brazil's Legal Amazon has seen significant infrastructure expansion, aimed at boosting soy and agricultural exports. Key projects include the paving of the BR-163 Highway, proposals for the Ferrogrão Railway, and the expansion of northern ports like Itaqui, While these developments promise economic growth by improving logistical efficiency, they come at a high environmental cost. The construction and upgrade of transportation routes have accelerated deforestation, fragmenting habitats, and threatening biodiversity and the integrity of the rainforest. The focus on infrastructure to support agriculture intensifies the pressure on the Amazon rainforest, pushing further into previously untouched areas. This expansion underscores the complex challenge Brazil faces in pursuing economic development without compromising the health of the planet's most vital rainforest.

But the destruction of rainforests is not just limited to soybean production and the need to get the soya exported out of the country. The very penetration of the Amazon leads to other 'dragging effects' in which more forest is cleared for cattle ranching and for illegal timber extraction than would otherwise occur.

**Amazon Destruction:** Going back at least 70 years, Brazil has unleashed a process of development in its Amazon Basin that is leaving vast areas shorn of trees. A combination of satellite imagery and verification on the ground suggests that, by 1998, the area of forest cleared in the Brazilian Amazon had reached some 549,000 square kilometres, hence about the size of France out of a total area as large as Western Europe and right now the total destruction measures around 800,000 square kilometres in the Brazilian Amazon alone, while large destruction is taking place in most of the nine Amazonian countries except for the three Guyanas, so we are looking at a total of about 1 million square kilometre cleared while of the remaining forests we see large degradation due to the feeling of the most valuable trees in many areas.

Then, in 2019, Jair Bolsonaro came into power. He stripped enforcement measures, cut spending for science and environmental agencies, fired environmental experts, and pushed to weaken Indigenous land rights, among other activities largely in support of the agribusiness industry. Between August 1, 2019, and July 31, 2021 — a period that largely overlaps with Bolsonaro's first three years in office — more than 34,000 square km (8.4 million acres) disappeared from the Amazon, not including many losses from natural forest fires. That's an area larger than the entire nation of Belgium, and a 52 percent increase compared to the previous three years. In no more than a few decades, Brazil has managed to

deforest an area far greater than that lost over the preceding five centuries of European colonization.

Meanwhile, because of government intervention, under President Lula and the climate minister Marina Silva, in controlling deforestation 2023 saw a significant reduction in deforestation again and the world is slowly waking up to the fact that losing the Amazon rain forest through the drying out and dieback of its trees, would not only send Gigatonnes of  $CO_2$  into the air, it would disrupt the total atmospheric hydrology of the planet and dry out huge agricultural areas crucial to global food production, not just in South America, but as far away as the American Midwest and Southern Africa.



#### Deforestation in the Brazilian Amazon accelerated under President Bolsonaro

Fig. 47. Deforestation of the Amazon over time – Graph courtesy Vox

The Amazon as Evaporative Force and Heat Pump: From a human perspective, the Sun moves across the Amazon Basin, in an East to West direction and the closed-canopy forest responds by opening up myriads of minute stomatal pores on the upper and lower side of each leaf. Each stoma or pore has a pair of guard cells which, on being stimulated by blue light from the Sun, become swollen and turgid, such that they move apart and, consequently, leave an opening for a gaseous interchange with the atmosphere. Meanwhile, the roots of the tree, with the help of a fungal mycorrhizal associate, draw water from the soil and subsoil into vessels, known as xylem, which take the water into the leaves of the tree and from there, if the guard cells are open, out into the atmosphere as water vapour.

The xylem system for taking water from the soil to the full height of a tall tree, in the case of the redwood sequoia, 100 metres (325 feet) is truly remarkable. The tree has no pumping system like a heart and, for the water to rise to such extraordinary heights, depends first on osmotic pressure at the roots because of the minerals dissolved in the water and second on reduced pressure in the canopy and branches as the liquid water in the leaves evaporates and passes out as vapour into the atmosphere. Capillary action and surface tension also play their part in the action of liquid water to rise upwards in narrow tubes. The pressure in the xylem can be well above atmospheric pressure and some tropical trees, if cut into such as to sever the xylem water channels, will send a fountain of water shooting up in the air. A large closed canopy tree in the Amazon Basin, taking up an area close to 80 square metres, will release as much as 1,000 litres of water vapour into the atmosphere each day. Evapotranspiration over the Amazon Basin amounts to an average of approximately 1.37 metres per year which, if distributed over the entire Basin of 7.6 million square kilometres, would give an average of 300 litres per day per tree, assuming that each tree encompasses a surface area of 80 square metres.

#### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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#### **Cooling the Planet with Plants**

We know from NASA that the planet is warming by 1.81 watts per square metre. 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 into account extreme climate events, be they massive floods, powerful storms, devastating droughts, and 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 that have been primarily responsible for keeping the Earth's temperature at levels that have enabled human beings to elaborate their agricultural systems and thereby 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°C, at which point we will be at a threshold, beyond which it will prove nigh impossible to return to cooler temperatures.

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.

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 was 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°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<sub>2</sub> 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°C above pre-industrial levels (280 ppmv) to zero by the turn of the 19th century. (Barrett, Peter, 1999 & Pagani, Mark, 2005).



### Fig. 48. Two graphs showing the correlation but not necessarily the causation between atmospheric CO<sub>2</sub> and global temperatures – Graphs 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 biomassforming and its role as a carbon sink. Indeed, if it were not for that transport of latent heat energy to Space, the upper atmosphere would have accumulated more and more heat, which is clearly not the case. (Harde, H. 2013).

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 is 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°C and we see today that the mean average temperature at the surface in the forested Amazon Basin is around 25°C rather than 30°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 cloudforming, acts like a vast, natural air-conditioning heat pump. Avogadro's Law tells us that at standard temperature and pressure, one gram-mol of water vapour (18 grams) will take up a volume of 22.4 litres, hence a volume-expansion of 1,200 times as liquid water transforms to vapour. That expansion, involving the breaking of hydrogen bonds between one water molecule and another, needs energy in the form of latent heat. The vapour, so formed, percolates upwards in the atmosphere until reaching an altitude where the reduction in temperature permits water vapour saturation and cloud-forming. Water vapour condensation releases the latent heat simultaneously with a sharp reduction in volume as vapour transforms to liquid. In effect, the latent heat of some 540 calories per gram of water, has been transported from the leaf surface to cloud-forming at an altitude of several kilometres, thereby moving upwards to an altitude where the air is much thinner and the greenhouse effect significantly reduced. The latent heat transported in this manner from the forests of the Amazon Basin, based on the 1.37 metres on average of evapotranspiration, amounts to as much as 41 per cent of the total solar input to the surface, namely 240 watts. In effect, as a result of condensation at cloudforming altitudes, the evapotranspired water vapour is carried upwards in the atmosphere at some 10 metres per second, which means that in less than two minutes it will have risen by more than 1 kilometre and will have brought about a significant cooling of the surface.

Further evidence of the cooling brought about by the spread of forests comes from the recent study of the cause of the mini-ice age during the 17th and 18th centuries, when, for example, the Thames in London froze over sufficiently for ice-skating. Alexander Koch and colleagues showed that the global carbon-budget of the 1500s could not be balanced until large-scale vegetation regeneration in the Americas was included. The Great Dying of the Indigenous Peoples of the Americas resulted in a human-driven global impact on the Earth System in the two centuries prior to the Industrial Revolution. Koch and his colleagues estimated that 55 million indigenous people died following the European conquest of the Americas beginning in 1492. Deadly disease therefore led to the abandonment and secondary succession of 56 million hectares of land which led to an additional 7.4 Pg C (7.4 gigatonnes of carbon) being removed from the atmosphere and stored on the land surface in the 1500s. Overall, including feedback processes, forest grow-back contributed between 47 per cent and 67 per cent of the 15-22 Pg C (15 -22 gigatonnes of carbon and equivalent to 7–10 ppm of atmospheric CO2) decline in atmospheric CO<sub>2</sub> between 1520 CE and 1610 CE seen in Antarctic ice core records. Koch and colleagues conclude that the Great Dying of the Indigenous Peoples of the Americas led to the abandonment of enough cleared land in the Americas that the resulting terrestrial carbon uptake had a detectable impact on both atmospheric CO<sub>2</sub> and global surface air temperatures in the two centuries prior to the Industrial Revolution. (Koch, Alexander., et al., 2019).

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

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

2010). That's 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).

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. 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 circulation. From their experimental results and fundamental physics, using a dedicated chamber in which they could cool a small portion of the contained air, 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.

- 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 is 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 the 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, such as during the unprecedented ones of 2005, 2010 and not least 2023, 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°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. (McIlveen, R., 2010) (Daniels, F. and Williams, J., 1966).
- 4) At cloud-forming altitudes, the air is thinner and the greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) 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°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, close to 70 to 80 per cent of the sun's energy, received at the surface of the rainforest, will be radiated to Space over time. (Harde, H. 2013).



**Temperature Celsius** 

#### Fig. 49. Clausius-Clapeyron equation. log P<sub>2</sub> - $(Q^*(T_2-T_1))/(R^*T_2 * T_1 *2.302) =$ log P<sub>1</sub> with Q, latent heat of evaporation 40.65 kJ mol<sup>-1</sup>, R, the ideal gas constant, 8.31 J K<sup>-1</sup> mol<sup>-1</sup>. P<sub>2</sub> = 1013.25 hPa, T<sub>2</sub> = 373 K. – Peter Bunyard

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°C. The unbearable high temperature is a consequence of the solar energy remaining trapped by the greenhouse gases 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 a considerable portion of the sensible heat of the Sun remains at the surface. In a nutshell, how hot or cold the regional surface is is a matter of timing and we must thank the rainforest for helping to keep the Earth's surface cool by means of its evapotranspiration.

5) 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 evapotranspiration generated over the rainforest and the subsequent

cloud formation led to a partial pressure change, as vapour transformed to liquid, such as pulling the column of air upwards. In fact, the H2O volume reduces by more than 1,200 times as each molecule of water vapour transforms into 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 Trades 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 ( $P_x$ ) is equal to the precipitation at the coast ( $P_0$ ) multiplied by the minus exponential of the distance (*x*) in kilometres from the coast divided by the average fallout length (*I*) of a water molecule from its evaporation to precipitation, the latter being given as 600 kilometres in accordance with Salati's isotope measurements:

$$P_X = P_0 exp\left[-\frac{x}{l}\right]$$

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).

#### 7.1 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).

The results of more than 100 experiments under different external weather conditions, ranging from temperatures as high as 25°C and as low as 5°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. 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°C relative to the average air temperature in other parts of the structure. That finding, in contrast to experiments where condensation was detected by ensuing rainfall and its collection, indicated that unidirectional airflow was a necessary correlation of condensation (Bunyard *et al.*, 2024).

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).



Fig. 50. 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 are seen by looking up the right-hand column. How much air was cooled per second depended on the rate of condensation and the resulting airflow. With no condensation there was no measurable airflow, even though the air at the cooling coils showed a temperature reduction of 10°C and a gain in density of 0.05 kilograms per m<sup>3</sup> − Peter Bunyard.



# Fig. 51. 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. The X-axis shows the time in seconds. More than 100 experiments gave results similar to that shown above. - Peter Bunyard

6) 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).



# Fig. 52. Schematic graph of the biotic pump pulling moisture in from the ocean and recycling water over land – Courtesy Dr Sheil, Dr. Mudiyarso and Dr. Ceci. The picture would have been complete if radiation out into space was added.

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<sub>2</sub> 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 kilowatthours (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).

#### 7.2 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<sup>14</sup>). Therefore, the additional global warming of the total Earth's surface over the course of a year amounts to the seemingly gigantic number of 2.91109x10<sup>22</sup> 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<sup>22</sup> 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°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.

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

The power derived from condensation was put to good work three centuries ago, in pumping water out of the tin mines of Devon and Cornwall. The Devonshire inventor, Thomas Newcommen, in 1712, devised an atmospheric steam engine pump which functioned in a cycle that used steam from a boiler to force a piston up a cylinder, and then, with a valve closed at the cylinder's base, allowed a small stream of cold water to flow into the cylinder, such that the steam abruptly condensed. The sudden condensation meant that the volume taken up by steam was sharply reduced by a factor of more than 1,000!

Atmospheric pressure, pushing from above, with a force of 760 millimetres of mercury or 14.7 pounds per square inch, then forced the piston down to the bottom of the cylinder. The time taken for the steam generated in the boiler to push the piston upwards would be relatively slow when compared with the instantaneous atmospheric force downwards. That's how the pump derived enough power to lift water from the lower levels out of the mine.

The biotic pump works on something of the same principle, but this time the condensation takes place when the air with its water vapour reaches high altitudes and the now-chilled air becomes saturated with water vapour. At saturation point the vapour condenses and clouds form. Obviously, the more that water vapour is transpired at the surface, the greater the quantity which condenses simultaneously at cloud-forming altitudes and the greater the thrust upwards of the column of air, as if it were the piston in Newcommen's atmospheric steam engine.

In the early 19<sup>th</sup> century, the Italian scientist, Amedeo Avogadro, came to the remarkable conclusion that, at the same temperature and pressure, the number of molecules of different ideal gases contained in a specific volume would be the same. As a result of Avogadro's Law, we know that  $6.02214076 \times 10^{23}$  is the number of molecules of a gas, such as oxygen or water vapour, in a gram-mole, hence the molecular weight in grams.

Avogadro's number would therefore apply to 18 grams of water, made up of 2 grams of hydrogen and 16 grams of oxygen, and to 32 grams for a molecule of oxygen, with its two atoms. We can also determine the volume occupied by one gram-mole of gas to be approximately 22.4 litres at standard temperature and pressure (0°C & 1 atmosphere) which, in the case of water, means that just 18 millilitres of liquid, given that one gram as liquid has a volume of 1 millilitre or 1 cubic centimetre, will transform, after evaporation, to a volume 1,244 times greater. Not only does that remarkable fact underpin the power of a steam engine, but it also has considerable consequences for the atmosphere when the water vapour in humid air condenses to form clouds. The abrupt volume change leads momentarily to a partial vacuum, followed by an implosion of air surrounding the point of condensation, which fills the space vacated by water vapour which has transformed to liquid. If enough water vapour is involved and the rate of condensation is high, the result will be a wave of air which moves vertically up from the surface to where clouds are forming. Vacuums are spaces waiting to be filled, and the upward flow of air will suck in the replacement from a horizontal current of air flowing over the surface. The consequence of cloud-forming on a big enough scale will result in a complete circulation of air and that is exactly what happens over the tropical rainforests of the Amazon Basin.

We are blessed with a lower atmosphere – the troposphere – which has an inverted temperature in which the surface of the Earth and, therefore, the furthest away

from the Sun, is warm at an average of 16°C, and the top of the troposphere, at an altitude of some 10 to 12 kilometres is truly cold at minus 60°C. The inversion is the result of the greenhouse gases trapping heat close to the surface, where they are at their most dense. The inversion has another, profound benefit for life on Earth because the coldness at high altitudes prevents water in the form of its vapour escaping into the stratosphere. If it were to diffuse into the stratosphere, the high energy spectrum of sunlight, short wave radiation, would split the water molecules by photolysis into their constituent atoms of hydrogen and oxygen and the hydrogen would escape the Earth's gravitational field and waft into Space. Without that inversion of temperature at the cold trap, the Earth would likely have lost most of its water.

#### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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#### 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<sup>2</sup>

NASA overheating per Earth's surface/yr = 2.91109x10<sup>22</sup> watts

5.2 million square kilometres Brazil Amazon 1 cm<sup>3</sup> (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°C would require the latent heat transport to Space of 2.25 million square km of tropical closed canopy rainforest. Implosion

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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.

Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

## Part II: Challenges and Solutions: The Recipe Book

# Regenerate the Great Forests and Grasslands

"Forests precede civilizations and deserts follow them" Francois-Rene de Chateaubri and Healthy Ecosystems Balance the climate

Contributing Author Dr. Rodger Savory Esq.

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.

## 8.1 THE COOLING POWER OF THE TROPICAL RAINFORESTS

While all ecosystems perform these functions, there are some major differences. Tropical forests are among the most biodiverse ecosystems on Earth, harbouring more than half of the world's animal and plant species, many of which are unique to small regions of subtly different ecosystems. There are tens of thousands of tree species and thousands of edible fruits, nuts and roots. Many plant species in rainforests have medicinal properties and are used by indigenous people for medicinal purposes. Western pharmaceutical science has only scratched the surface of the treasure trove embedded in the sheer endless biodiversity of these areas. Tropical rain forests have made evapotranspiration an art through the development of angiosperms or flowering plants which conquered the world, especially the then-tropical regions, some hundred million years ago. Their proliferation is connected to a large drop in the temperature of the planet through the increased photosynthesis and carbon sequestration that accompanied that evolutionary development. The net result of such activity was the drawing down of atmospheric carbon from 3,000 parts per million to 280 ppm some 250 years ago when the industrial revolution came into being.



Fig. 53. Serengeti Landscape in Tanzania, Africa – Photo by Javier Hueso/Shutterstock

Tropical forests are the champions of cooling not just their own environment but the whole planet. They are masters in regulating their microclimates, but also the macroclimates, which they regulate principally through the creation of atmospheric rivers through the biotic pump function. The moisture streams recycled from the Amazon alone reach out all the way to the southern part of South America, as well as via the Caribbean to the US Midwest, via the Pacific to the West Coast of North America and even to South Africa. Similar stories can be told about these planetary teleconnections for other moisture streams.

The prolific photosynthesis that takes place in the rainforest also is a major factor in the production of oxygen. Without large-scale photosynthesis and the production

of free oxygen humans would cease to exist. The Amazon rainforest alone has a global cooling effect on the planet of 0.5°C, almost entirely caused by water cycle mechanisms. If we could magically add tropical rainforests the size of the Amazon to the current area today, the planet would start on a cooling trajectory very soon after. Given their function in cooling the planet, the protection and regeneration of the world's great forests, especially those of the Amazon Basin, has to be of the highest priority.

The rate at which tropical rainforests can be restored varies, based on multiple factors, including the starting condition of the land, the extent of previous degradation, local environmental conditions and, not least, the allocation of financial, labour, and expertise resources. Depending on the initial state left after deforestation, we have identified three ways by which to bring about restoration.

First, and involving the least intervention, is natural regeneration, when forests are given free rein to recover on their own. Clearly, Natural regeneration is the most cost-effective method and usually results in a biodiverse and resilient ecosystem. For an area which has suffered minor disturbances and with a remnant forest nearby, natural regeneration can yield substantial recovery in as little as 20 to 40 years. For more heavily degraded areas, the timeline might extend to decades or even centuries. From personal experience, the authors have witnessed the regeneration within six to seven years of 15-metre-high trees, made up mostly of pioneer, secondary species like Cecropia. The seeds of such pioneer species germinate when exposed to direct sunlight and are the first to colonise an exposed area. By way of contrast, primary forest species develop from seeds that are shaded from direct sunlight and therefore their germination can follow the coverage provided by species such as Cecropia.



Fig. 54. Morning Fog in dense Tropical Rain forest – Photo by Stephane Bidouze/Shutterstock Second, we can employ what has been called assisted natural regeneration (ANR) which basically comprises a set of practices to reduce barriers to natural forest regeneration, such as soil compaction, competition from grasses, or repeated disturbances. Activities might include selective thinning, control of invasive species, or protecting young trees from herbivores. Depending on the level of intervention and the initial condition of the land, recovery in ANR plots can be faster than pure natural regeneration, possibly seeing significant recovery in 15 to 40 years. By the early planting of useful native species that would normally only grow after a decade or so, the process of regeneration can be accelerated. If the area to be recovered still has tree-stumps that have survived a fire or a clear cut, it may prove possible to stimulate the growth of suckers and saplings from the original tree and, if so, encourage regeneration.

Reforestation involves planting trees and other vegetation in areas where forests have been drastically reduced or removed. This is the most resource-intensive method but can accelerate forest recovery, especially if the goal is to establish a particular set of tree species or to stabilise an area quickly. With intensive care, planted trees can establish themselves within a few years, and a semblance of a forested landscape might emerge within 10 to 20 years. However, achieving the complexity and biodiversity of an old-growth tropical rainforest can take many decades, if not longer.

Last but not least, we can reverse the damage through multi-species, multi-layered agroforestry, where cropping is integrated via corridors within the surrounding forest. Multispecies agroforestry mimics natural forest structures by integrating diverse plant species, providing habitat for various wildlife species and helping to maintain or increase biodiversity in the landscape. The diversity can also facilitate the natural migration and establishment of other forest species. Agroforestry systems enhance soil quality by improving soil organic matter, increasing nutrient availability, and reducing soil erosion. A healthier soil profile is crucial for natural forest regeneration. Trees in these systems help regulate the water cycle, ensuring water retention in the ecosystem, supporting nearby forest patches, and facilitating forest regeneration. Multispecies agroforestry can act as transitional areas between deforested lands and intact forests, reducing detrimental edge- effects like wind penetration and sun exposure. By attracting various wildlife, especially birds and mammals, these systems can facilitate the dispersal of seeds from nearby forests. They also help sequester carbon, playing a role in climate change mitigation by acting as carbon sinks.

The economics of agroforestry are complex, but in general well-maintained agroforestry production areas can increase the practitioner's income by two to even ten times compared to cattle rearing or seasonal monoculture crops. However, the transition from open field production to agroforestry is not straightforward, primarily because it can take three to seven years before the agroforest gives enough income and those providing credit are rarely prepared to wait that long. Secondly, the transition needs trained-labour if the expected income is to be realised and thirdly, the harvested products need market-access.

Nevertheless, agroforestry becomes an appealing option when local communities realise how its application leads to diversified and sustainable income sources, based on a variety of crops, timber, and non-timber forest products. The hope is to deter them from opting for more destructive land uses, like forest clearance and cattle ranching. Additionally, by offering products that might otherwise be extracted destructively from natural forests, agroforestry can reduce direct pressures on those forests.

Agroforestry systems can also serve as hubs for education and cultural practices, fostering an appreciation for forests and their many services. However, the effectiveness of these systems in supporting tropical rainforest regrowth depends on proper management, the scale and connectivity of the plots, and the socioeconomic, cultural, and ecological contexts of the region. When appropriately designed and managed, multispecies agroforestry can play a vital role in supporting the regrowth and health of tropical rainforests.

As described earlier, restoration of tropical forests on a sufficiently large scale could stop the planet from heating up further and we calculate that 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.

# 8.2 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 is the Eurasian steppe, stretching all the way from Hungary to China, the North American Great Plains, and the grasslands of South-America such as the Pampas, Cerrado, Llanos and Gran Chaco. In Africa, we have 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 savannas. 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 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<sub>2</sub>, thereby putting carbon back in the atmosphere for photosynthesis, as part of the natural cycle between vegetation and 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, 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.

The behaviour of grazing animals is shaped by the presence of pack-hunting predators, as worked out by Rodger Savory. During the rainy season, the predators cause herding animals to disperse over vast expanses, allowing them to calve in smaller family units and so elude continuous predator surveillance. With most animals calving within a brief window, their wide distribution makes it impossible for predators to prey on all the vulnerable young.

However, as water sources dwindle during the dry season, the herds consolidate near smaller streams, initiating their migrations in search of fresher pastures. Predator presence causes the herds to remain closely knit for safety. This close congregation leads to a high concentration of dung and urine in a given area. Since no species prefers grazing on land polluted with its own waste, herds must migrate

and do not return until microorganisms have fully processed their waste, eliminating any residual odour.

The concentration of dung attracts vast swarms of dung beetles, facilitating significant tunnelling and channel creation. The deposited urine enriches the soil with nutrients beneficial to bacteria and fungi, effectively hydrating lands distant from primary water sources. Such constant migration of herds across grasslands also played a pivotal role in seed dispersion, enhancing the variety of plant species. The soil gets aerated by trampling of the millions of hooves that also make indentations creating countless little puddles when it rains. This micro water management helps the water to infiltrate efficiently and together with the nutrients to keep the community of soil organisms alive and plants growing. Large, roaming herds are essential to preserving the vitality and diversity of grassland ecosystems. These ecosystems, in turn, sustain a vast array of life, from insects and birds to apex predators.

In bygone times, when the plains were populated by huge roaming herds of ungulates, such as bison in the Midwest, fires ignited by lightning were infrequent at most. Lightning- triggered fires are unlikely to spread when dormant forage is covered by the diligent work of dung beetles. Consequently, by the mass-killing of bison, humans inadvertently exacerbated the number and extent of wildfires ignited by lightning.

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 the 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 in as much 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.

# 8.3 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, more heat, in a vicious circle. According to Indigenous voices, the boreal forests are responsible for keeping the polar areas frozen.

All kinds of feedback loops kick in with the polar amplification that is a result of these disturbances, such as the melting of permafrost and the forming of so-called drunken forests as the ground beneath them turns to mush. Of deep concern is that the permafrost- melting is increasing the escape of methane which, with its greenhouse heating potential 60 times greater than carbon dioxide, is adding considerably to planetary warming. For the health of the planet and to achieve climate stability, we need both boreal and deciduous forests. The removal of forests in Europe has dried out parts of the Eurasian continent, all the way to northern China and reforestation would help rehydrate what is the largest continent on Earth. The situation on the Pacific coast of North America is currently somewhat better, as the rainforests there have not been entirely removed. But damage to the forests there is considerable and the tracts remaining are under threat from logging and more recently from disease. If we want to combat the amplification of climate change in the Arctic, we must reforest the clear-cut areas with native forests and fiercely protect what is left.

### 8.4 CALL TO ACTION

We need to institute ambitious million-hectare protection and regeneration projects in the tropics, including regenerative food production through agroforestry schemes.

For the tropics, the priority areas are: The Amazon region, South American Cerrado, Pantanal, and Meso-American countries from Nicaragua northwards. West- and Central Africa, mountainous regions of Eastern Africa, Northern Kenya, Horn of Africa, Botswana, Namibia, Zambia, Zimbabwe, Mozambique, Malawi, Southern, NW and NE India, Myanmar, Thailand, Cambodia, South-China, on Sumatra, Kalimantan, West-Papua, North Australia, mangroves worldwide, and even regreen some deserts.

## 8.5 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.

Some 200 million householders in China, India, Indonesia, Bangladesh, and Vietnam, carry out smallholder farming, as do 220 million families in Africa and the Middle East and about 70 million families in Latin America. Together, all these householders work about 750 million hectares of land, which is an area twice the size of India.

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. Global acupuncture points for this work, apart from the NE side of the Amazon rainforest, could be coastal Pakistan, Oman, Yemen, the Horn of Africa, and the Sinai to continue the Indian monsoon moisture flows over the continents like they probably once did: all the way over the Arabian Peninsula, Mesopotamia, the Sahel and the Mediterranean, areas that were thickly wooded before huntergatherers started to settle and slowly turned to agriculture and animal husbandry.

### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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# Rehydrate the Lands by Restoring the Water Cycles

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Fig. 55. The Water Cycle – Courtesy US Geological Service

Viewed from space, the Earth appears as a blue dot covering 75% of the Earth's surface with water, which is in constant motion across our planet in clouds, oceans, rivers, ground, human cells, and all living organisms. At the same time, water is present in all its *four* states: gaseous, liquid, solid and life.

**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 and 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 in seawater some 3.5 billion years ago. This was the beginning of aerobic metabolism and enabled the evolution of higher organisms, including higher plants.

The changes in evapotranspiration impact the water cycle.



Fig. 56. Some of the oldest life forms on Earth, Stromatolites – Peter Bunyard, Climate Chaos (2010)

**The biotic pump** phenomenon explains how we can restore the small water cycle: evapotranspiration of rainwater through plants and moisture can intensify 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. Not incidentally, 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. (Don't be misled by the name; the "small" water cycle. The term itself was coined in *Water for the Recovery of Climate.*)

# 9.1 HOW WOULD OUR FUTURE LOOK LIKE WITHOUT FRESH WATER?

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. Anastassia Makarieva and Antonio Nobre call deforestation a "catastrophic situation" that threatens to disrupt Earth's climate. We have known since 2007 that the biotic pump processes that maintain dominant wind patterns, bringing humid air from the ocean to land, are threatened by deforestation. With the 2023 drought in mind, we are already experiencing the collapse of the biotic pump over the Amazon Basin.

Americas: The Amazon rainforest has enormous implications for the agriculture of the whole of the Americas. Southern Brazil, northern Argentina, and Paraguay depend for rainfall on the moist Atlantic trade winds, which cross the Amazon basin and then are deflected southwards by the Andes. The American Midwest is watered from the same source by the moisture deflected northwards; drought in the interior US inland is a culprit behind the increased frequency of hurricanes on the East Coast.

**Asia**: Indonesian forests likely determine the precipitation regime in the adjacent oceanic regions.

**Europe**: The biotic pump of the boreal forest zone impacts atmospheric moisture transport from the Atlantic Ocean over several thousand kilometres. Deforestation in European Russia disrupts this mechanism causing abnormal warming and droughts. Europe depends climatically on the boreal forests of Russia.

Australia: Owing to deforestation, there is no biotic pump on this continent: oceanic moisture cannot penetrate the Australian continent regardless of how much moisture there is over the ocean. Yet during the wet season, it precipitates in the coastal zones causing floods.

Also, since 2007, a group of Eastern European researchers have developed an intriguing examination of how humanity's attitude toward precipitation has gone counter to nature, with the coming of an industrial approach to water management. In *Water for the Recovery of Climate - the New Water Paradigm*, the authors examine how we can alter our approaches to better serve the needs of ecosystems and humanity. Authors first pointed out that the runoff from the modern infrastructure of roads, roofs, and impervious surfaces drains away 760 km<sup>3</sup> of rainwater from the continents annually, contributing to rising sea levels by 2.1 cm (almost 1 inch) every decade, or 10 cm by 2050.

Vision. Is it possible to heal our climate? Yes! With a new water paradigm shift!

Extreme weather events are popping up worldwide, like in a game of whack-amole, correspondingly to the speed of human-made land changes and a fast rate of replacement of natural ecosystems with impervious surfaces such as concrete, asphalt, solar panels in place of farming land, or glass or plastic greenhouses. People design their liveable spaces for comfort, nice and dry, drain wetlands, straighten the waterways into convenient drainage or irrigation canals, and engineer intensive agriculture without regard for ecosystem function. Tarmac (MacAdam) expansion cannot replace breathing and cooling nature systems. Nature needs to breathe! Sun-powered water cycle needs abundant water and moisture on the ground and in a soil sponge to perform the miracle of life: photosynthesis!

The forest plays an essential part in the water cycle and climate regulation system by recycling the water through evapotranspiration. Should we focus on reducing carbon emissions first and, in the meantime, allow changes in land use and land cover (LULC), we will cross a threshold of Earth's ability to hold a liveable and breathable atmosphere.



#### Fig. 57. Land degradation alters hydrological cycles. Anthropological runoff dries out continents and leads to additional sea levels rise – Graph courtesy Michal Kravcik/ WaterHolistic.

More than half of the water molecules that fall in the western Amazon have previously fallen on the rainforest much further to the East. In its absence, it would be reasonable to expect a corresponding decrease in regional precipitation, which would be calamitous, but the actual effect could be much worse. Two Russian physicists, Victor Gorshkov and Anastassia Makarieva, claim that forests, not temperature, are the main drivers of winds.

They base this on the previously unconsidered drop in pressure that occurs when water passes from gas to liquid state in condensation. So, ecosystems that maintain a moist atmosphere—as rainforest does—draw in air and moisture from elsewhere. This could explain the curious fact that precipitation in the western Amazon is higher than it is upwind, despite leakage in run-off at every revolution of the local water cycle. The biotic pump principle caused a stir in Western academia in 2010 when it was put forward in the Bioscience journal. It supports the point that conserving forests is often essential to maintaining a terrestrial water cycle. In other words, water constantly moves over land because the woods and plants pull it from the oceans.

The scientists look at the law of mass conservation and show that forest transpiration can regulate climate. The existing life evolved in the current state of homeostasis in which biological systems preserve stability in a self-regulating cycle. (See Chapter 7).

If the atmosphere is sufficiently wet, forests control atmospheric moisture convergence: increased transpiration enhances atmospheric moisture import and yields water.

Conversely, if an atmosphere is already dry, we have a problem. The increased transpiration reduces atmospheric moisture accumulation and water yield. This previously unrecognized dichotomy can explain the otherwise mixed observations of how water yield responds to re- greening.

Trees are 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.

Call to Action: How to quench our thirst and rehydrate our lands?

Small water cycles recharge the ecosystems. Human-made inventions increased the volume of water in the atmosphere by reducing the function of ecosystems to transpire and evaporate. In other words: Small water cycles feed life in the ecosystems, not storms in the large water cycle. The absence of small water cycles intensifies storms. How? Wetlands reduction, corrupt agricultural practices, and negligent stormwater management reduce the watershed function and cause the landscapes to dry up. Current human landscapes treat rainwater as inconvenient waste and dispose of runoff anytime the rain falls on the ground.

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. What are the causes and the outcome of such practice? Eventually, they must deal with the heat waves in their cities due to diminished moisture in the ecosystems (loss of evaporation and groundwater recharge. A decade-old data tells us that urban and real estate development is annually responsible for 57,000 km<sup>2</sup> of global runoffs. In the pursuit of food supplies, people cut annually about 127,000 km<sup>2</sup> of forests and convert them into arable land. Corrupt agricultural practices cause an annual drying up of over 200,000 km<sup>2</sup> of farming land. To illustrate the point, Michal Kravčík analysed the hydrological regime changes in Slovakia and appraised the rain runoff in Slovakia, amounting to 250 million cubic metres. An enormous amount of water once abundant in the small water cycles in that region now drains away in sewage infrastructure. Globally, people worldwide drain away 760 cubic kilometres of rainwater from the continents annually. We are talking about 760,000,000,000 m<sup>3</sup>!

Stormwater runoff makes its way ultimately to the sea. This vast amount of water was previously circulating in the regional ecosystems, where small water cycles used to recycle it: water seeped into the soil, promoted photosynthesis, bound carbon to biomass and soil, evaporated, formed clouds, and subsequently formed

rain in that region. That's a lot of water! Let that sink in. Excuse the pun. Let the water sink in the watersheds. Slow it, sink it, spread it! That is the action plan!

	NT
Old water paradigm	New water paradigm
The water on land does not influence global	An important factor in global warming may be the
warming, which is caused by the growth in the	change in the water cycle caused by the drying and
volume of greenhouse gases produced by human	subsequent warming of continents through human
activity.	activity.
The subject of research is the impact of global	The subject of research is the impact of changes in
warming on the water cycle.	the water cycle on global warming.
Urbanization, industrialisation and economic	Urbanization, industrialisation and economic
exploitation of a country has minimal impact on the	exploitation of a country (over about 40% of the
water cycle.	area of the continents) has a fundamental impact on
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	the influence of the water cycle.
The impact of humanity on the water cycle is	The impact of humanity on the water cycle is at
negligible and changes in the cycle cannot be	present considerable and its changes can go in both
reversed by human activity.	directions.
Adverse climatic trends will increase, mitigation	If the new approach to water is applied, a possible
can perhaps be expected within a horizon of	recovery of the climate can be expected within
centuries.	decades.
Interest in the large water cycle, which seems	Interest in the small water cycle dominates.
difficult to influence, is dominant while the	
significance of the small water cycle is trivialized.	
The reason for extreme weather effects is global	The reason for extreme weather effects are changes
warming .	in the water cycle.
Global warming and extreme weather effects are	Global warming can exist without extremes of
inextricably linked.	weather, extremes of weather can exist without
	global warming.
Global warming is the main climatic problem for	Extremes of weather are the main climatic problem
humanity.	for humanity.
Vegetation is not ideal from the viewpoint of global	Water and vegetation alleviate unwanted
warming because it has a low albedo (reflectivity);	temperature differences; cloudiness moderates the
water vapor again increases the greenhouse effect.	intensity of solar radiation falling on the Earth's
	surface.
Speaks about the atmosphere as a greenhouse	Speaks about the atmosphere as a protective
covering of the Earth.	covering for the Earth.
Rising ocean levels are a result of melting icebergs.	Rising ocean levels are a result of melting glaciers
	on land, but also of a decrease in soil moistures,
	levels of groundwater and the state of other waters
	on landmasses.
Rainwater is an inconvenience and needs to be	Rainwater is an asset that needs to be retained in
quickly removed.	soil/plants'
The main source and reserve of water is surface	The main source and reserve of water is
water.	groundwater.
There is an impersonal attitude by owners and users	A change in the anonymous approach to rainwater
of land (citizens, companies and offices) towards	on an individual's land and the creation of a spirit of
rainwater in a territory.	shared responsibility for water resources.
Water is used only once for one purpose and then is	Water can be used for more purposes, then purified
sluiced away.	and recycled
Water supplied to communities primarily through a	Water supplied through a system divided into
system of mains with "potable" quality water.	potable and utility water.
iviutual isolation of public policies in relation to	Policies in relation to water are based on a thorough
water.	perception of water in the scope of a functioning
	water cycle in a country.
A sectoral approach to managing water resources	territory
Uli ialiu.	territory.

A comparison of starting points and approaches according to the old and the new water paradigm

## 9.2 GLOBAL ACTION PLAN

For climate change because of anthropogenic drainage and vegetation depletion, the major necessary intervention is to restore water in dry, damaged ecosystems, a measure which can be achieved with rainwater retention and soil erosion control. 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. This can be accomplished; it is only necessary to mobilize stakeholders, from local and regional to national, international, and global levels.

Natural landscapes provide a "giant soil sponge" with ample vegetation, deep root systems and soil life that absorb water easily, replenish groundwater, and release cooling cloud-forming water vapour, via plant transpiration, into the atmosphere to later fall as rain. This is the essence of the regional, or small water cycle. Stormwater runoff is a major source of water pollution as well as contributing to flooding, drought, and diminished fresh water supplies. Furthermore, less water into the land leads to less plant growth, the plants so greatly needed as prime regulators of climate.

A critically important yet simple way for humanity to work with nature is being demonstrated around the globe by farmers, urban planners, foresters, and homeowners rediscovering the many benefits of allowing the rain and snow that falls on the land, to soak in where it falls.

Community actions add up to global action:

#### Global Action Plan for the Restoration of Natural Water Cycles and Climate Implementation of the Global Action Plans as National Action Plans:

To achieve combined multi-sector and economic incentives of the Global Action Plan (GAP) at the national levels, we recommend an integrative approach on two levels:

- Implementation of National Action Plans (through integrated projects for permanent restoration of water in small, regional water cycles), via watershed, or river basin projects.
- 2) Implementation of national plans into economic processes of public and private business sectors via multiple economic incentives.

The New Water Paradigm White Paper prepared for the 2023 UN Water Conference. Source: <u>https://www.mpsr.sk/en/index.php?navID=54&id=84</u>

Why are trees and plants needed as prime regulators of climate? Plants are reservoirs of water. That plants emit oxygen has long been known. That they store carbon has come to people's attention only in recent years. That plants

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

transpire, and also make rain is a fact that has not been much known. When humans alter the land, they change the hydrology of watersheds and, thus, the water cycle. Water, carbon, and oxygen are what make our planet habitable. The plants and all living organisms contain the "fourth environment" for water.

Trees are often depicted as the lungs of the planet. People like to make analogies. But could any human breathe without first having water to drink? Watersheds, plants, and biodiversity regulate climate.

#### From Local action plans to Global Action plan

Territorial level of action plan	Examples of Action Plans – see references as well	Target of increase water retention capacity within 15 years
Global Action Plan (GAP)	GAP 2015	750 km <sup>3</sup>
National Action Plan (NAP)	NAP Slovakia 2010	250 000 000 m <sup>3</sup>
Regional Action Plan (RAP)	RAP Kosice region, Slovakia 2018	60 000 000 m <sup>3</sup>
Community / village / city / local action plan (LAP)	Community / village / city	From 100 000 m <sup>3</sup> and more in the cadastral area
Individual / Citizen Action Plan	A citizen of the planet	100 m <sup>3</sup>

1) As a first step, it is necessary to slow down to stop the decrease in water retention capacity due to changes in its use. New public policies for urban development and agriculture will help

2) By preparation and implementation of the adaptation (nature based solutions, new landscape features, new water retention measures, new water holdings, blue and green infrastructure) and management measures (regenerative agriculture, rainwater harvesting in cities, communities, in forest, and agricultural land) we will increase significantly lost water retention capacity

We are excited to be sharing a renewed understanding of the natural cycles of rainwater and the land. It's a worldwide revolution that is blending ancient wisdom with modern science, to transform both cities and rural areas into new green and thriving spaces. We are starting to restore our regional climates by following nature's ways of cycling water, and we all can learn and be inspired by success stories across the globe. We believe nothing is more important to the wellbeing of earth and humanity than this knowledge: by allowing rainwater and melted snow to move in its natural cycle in the land, and the atmosphere immediately above our regions, we can solve a large number of environmental and human needs simultaneously. The basic action needed is simple—soak up rain and snowmelt in the land— the methods are many, and the results are profound.

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. Jan Pokorný and his three decades of applied solar energy research at Enki NGO helped us to realise that farmers should be seen by society as the 'managers of our landscape'. Their experience is in tune with their local environment - they receive a direct feedback-mode with the properties and harmonic patterns of their own locality. Farmers can rescue society's life-giving 'hardware', and the land, and provide sustainable management.

Many people in cities, suburbs, farms and ranches—are already successfully restoring these processes. The co-benefits are enormous, providing resilience to extreme weather events, as well as improvements in clean water supplies and food security.

**Investments and Benefits**: Forests are crucial in all sorts of ways because of the manifold services they provide. Western taxpayers need the Amazon rainforest to control their climate. Brazil needs it to help feed its rivers and generate hydropower. Amazonian soya farmers need it to guarantee them decent rainfall. Changing current policies to protect forests in Brazil and across the tropical world, is a daunting task. But it is not impossible—and it must be done. The cost of failure would simply be too great.

These conclusions offer good news for global restoration, where reduced global runoff has often been predicted. Our results indicate that restoration can transition through this negative phase into a context when re-greening can profoundly improve water yields and overall availability. Rigorous interdisciplinary scientific planning merging ecology and atmospheric science is required to achieve this.

As governments start to be hit by droughts, water shortages, and floods they are beginning to announce plans to deal with the growing demand for a dwindling resource. Many communities and even whole countries are imposing water restrictions and rationing. But it is often only for households and not the big users of water, such as big water guzzling agro- industrial farms, leading to charges of injustice. For example, the best time to prepare for a drought is when it is raining. That's why the world needs to focus on two major investment strategies to rehydrate our continents:

- Rainwater retention measures to recharge groundwater and prevent soil moisture loss, using forests and the potential of vegetation for storing water, including old-growth forest preservation and afforestation.
- Integrated watershed restoration and nature-based solutions.

#### 1. Global Action Plan (GAP): Integrated Reconstruction Projects to Restore Small Water Cycles

https://sdgs.un.org/partnerships/white-paper-water-climate-healing-new-water-paradigm

Through partnerships for river basins, necessary work would include preparation, processing, and realization of integrated reconstruction projects for the restoration

of small water cycles in the basins, achieving funding, assuring long-term operation and maintenance of all technical measures, and managing the water and landscape works achieved, as well as buildings and other necessary additions or changes to existing infrastructure. These are to be created through a declaration of the common goals of the partners in accordance with the GAP, to take responsibility for the ecological integrity of the basin.



Fig. 58. Overview of Climate Recovery Plan by Michal Kravcik

Multi-sector participation in startup projects, activated with the support of the World Bank, especially at the beginning stages, will be possible only through active participation not only of governmental agencies but also scientific and civic sectors. This may require significant changes to existing institutions that manage basins, which will lead to restructuring and more effective actions.

#### 2. Economic Benefits of the GAP for Individual Nations

Nations will achieve legislative changes for the effective dynamics and timeliness of their National Action Plans (NAPs), as a result of feedback processes provided by the GAP; such processes will ensure the full-scale implementation, addressing a wide variety of environments and levels of ecosystem damage, and thus increase widespread value and productiveness of landscapes. Furthermore, the GAP's implementation, through NAPs, will create new opportunities for products and services, thus providing new jobs and decreasing unemployment levels nationwide.

As a result of the implementation of the NAP Program in each country, rainwater will be retained in the landscape, resulting in effective preventive measures to reduce the risk of flooding and drought, and mitigate climate change; the retained water will also, in many cases, become a critically important resource for increased agricultural, urban and commercial usage; these opportunities can be further developed and promoted by governments, public institutions, and private business and civil sectors. Depending on the type of landscape in which the specific projects will be implemented, rainwater will be retained in revitalized regions through various accessible, effective, and multifunctional methods based on renewable natural resources. The first realization is that existing natural areas, particularly *wetlands* must be preserved or restored, including diverse native plant, animal, fungal and microbial species. *In landscapes heavily impacted by human activities,* however, restorative interventions are needed; effective rainwater retention and benefits realized by such measures include the following:

**2.1.** In forested lands, basic measures for rainwater retention include infiltration trenches and water bars in logging roads; simple rainwater catchments of earth, stone, and logs or brush to repair gullies; followed if necessary by replanting of harvested trees; restored forests will 1) provide a source of natural high-quality drinking water, increasing current and future limits of economic development of large areas, both regionally and nationally; 2) increase the volume capacity of water sources, thereby increasing the energy potential of watercourses, while at the same time moderating movement of water through the landscape and thus reducing both flooding and droughts; and 3) provide far-reaching climatic benefits of forests including the cooling effect of shading afforded by the tree canopy; conversion of solar energy into latent heat via transpiration, and the formation of rain clouds via the mechanism of the biotic pump.

**2.2.** In agricultural and rural areas, measures to increase rainwater retention include water catchments in the form of farm ponds and swales; in addition, much improved agricultural methods will incorporate cover crops and no-till methods for grain, vegetable, and fruit production; holistic intensive grazing management of livestock is of particular interest for the world's pasture and natural grassland areas. Such measures will 1) increase the production potential of agricultural land by preventing moisture loss and subsequent degradation of the land, as well as reducing erosion and pollution, and increasing biodiversity while providing efficient reservoirs suitable for the growing of crops and watering livestock; 2) economically strengthen agricultural activities by increasing production, as well as diversification, for example by using created farm ponds for raising aquatic flora and fauna; and 3) create an attractive environment for economic development of the countryside for agro-tourism and educational programmes.

**2.3.** In urban landscapes and for road infrastructure, rainwater retention can be achieved by the use of innovative practices, such as green roofs, rain gardens, vegetated swales, rainwater storage tanks, and other bio-technical systems for conserving water necessary for municipal services, such as fire-fighting and road-cleaning; and integration of other innovative approaches to water management, for example by sophisticated and highly effective biotechnological municipal

wastewater treatment. Such measures will be an effective means to 1) achieving economically feasible measures for climate restoration, such as cooling of high temperatures induced by heat islands in intensively developed environments typically made arid through extensive impervious surfaces, 2) reducing flooding and pollution related to the rapid flushing of stormwater over impervious surfaces and via storm sewers into rivers, and 3) increasing vegetated green areas for increased aesthetic, health, and recreational value for urban dwellers, as well as opportunities for local food production.

**2.4.** Particularly in arid and desertified regions of the world, all of the aforementioned measures for rainwater retention will be of further benefit by 1) increasing water and food security; 2) strengthening social cohesion and solidarity, and reducing conflict over water rights; 3) spurring economic growth, and 4) restoring native ecosystems and biodiversity. Through practical implementation, revitalization, and conservation of rainwater in all countries, the GAP will not only directly fulfil its main objectives — building flood prevention measures and reducing climate change risks — but will also create specific secondary social and economic benefits, incentives for innovation and demand for new technological products and services, thus creating long-term opportunities for higher employment and economic growth.

Farsighted strategic thinking targeted support of innovation, and introduction of new processes and products in the field of efficient use of recovered rainwater from restored small water cycles, present a unique opportunity for businesses and investors to establish themselves in a sector which has the prospect of dynamic growth in a global context. In coming years, technology companies in this sector could create for themselves a significant competitive advantage in the global economy, at a time when knowledge, skills, technology, technical solutions, machinery and production equipment and related services of the GAP will be in high demand. Markets will grow in the economies of developed nations that already have high concentrations of intensive urban areas (Europe, USA, Canada, Japan) as well as in markets in economies with large industrialization potential (China, Russia, India, Argentina, Brazil, countries of the Balkans). Extraordinary demand for products in this sector can already be observed in the countries of the Middle East (Saudi Arabia, Israel, Turkey), North and South Africa (Algeria, Morocco, Egypt, Libya and South Africa) and Australia. The markets of all countries will provide sufficient business and investment opportunities in the mid-term as a result of their intensive urbanization and insensitive construction of industrial and transport infrastructure in the recent past.

## Water and Carbon: Two Sides of the Same Coin. Photosynthesis is the Engine that Powers up the Water and Carbon Cycles:

The Earth's need for forests to soak up carbon emissions is almost limitless. Saving the forest that is left should therefore be considered a modest aim. But even that will require huge improvements in forest management, such as reforming land registries and tightening up law enforcement. Above all, it will require governments to prize forests very much more highly than they do now. Many more reforms required outside the forestry sector are required: in land-use planning and rural development, in agriculture, energy and infrastructure policies, and much else. It will also require politicians to get serious about climate change. However, one cannot look at climate change as a function of carbon dioxide. Climate change mitigation needs to look beyond technical solutions to carbon capture, such as recent \$1.2 billion investment plans. What hope of survival have forests, especially the tropical sort, most precious and most threatened? Large-scale defences are now being marshalled by governments, NGOs, scientists and investors, chief among them an international endeavour known as Reduced Emissions from Deforestation and Forest Degradation, or REDD. Launched with \$4.5 billion, it was based on the idea that rich countries should pay poorer ones not to cut down trees. REDD needs to be revisited.

#### How to Remain to be the Guardians of Life in the Galaxy?:

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 work 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."

By recognizing that all regions must have healthy small water cycles to keep local climates moisturized, energized and moderated, the New Water Paradigm shift will help to open our minds to all the ways that water is circulating, not just in the clearly visible rainfall. Plants, particularly trees, perform an amazing cooling and moderating role in the small water cycles. The vapour transpired by trees stores solar energy as latent heat. This energy is later released in colder locations, due to condensation of the vapour and it finally irradiates to space as low-frequency infrared. 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.

Most tropical deforestation is the result of expanding commercial ranching and agriculture, driven by rocketing domestic and global demand for food, fibre and biofuel. Palm oil, soybeans plantations, large-scale farming for crops produced for ethanol and grain-feeding of cattle, greenhouse constructions, and tamarack urban planning all contribute to land degradation, and thus loss of evapotranspiration. On the contrary, regenerative and syntropic agriculture and agroecology sustain a healthy water cycle.



Fig. 59. The Value of a Forest – Image courtesy of Michal Kravcik/Waterholistic

### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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## **Restoring the Oceans**

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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 swaths 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 the 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 have now been hugely depleted and the reefs and food webs that fortify habitats and protect coastal communities from storms and erosion are in critical condition.

## **10.1 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.

### **10.2 THE STORY OF THE SALMON AND THE FORESTS**

A beautiful example of this interaction is that between salmon and forests. These amazing fish are 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.

### 10.3. 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<sub>2</sub> 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.

### **10.4 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.

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.



Fig. 60. Overview of Coriolis effect on Wind patterns and Thermohaline Circulation – Courtesy NASA

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 the carbon sequestration capacity of the oceans in tens of gigatonnes of CO<sub>2</sub> 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<sub>2</sub> levels and temperatures from going beyond the 1.5°C `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.

#### **10.5 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.

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 uses 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 the 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.



Fig. 61. 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.

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.

#### **10.6 OPEN OCEAN**

The Fig. 63 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.



Fig. 62. Representation of ocean circulation partly driven by salinity stratification- courtesy Phil Stoffer at Miracosta Education.



Fig. 63. Ocean Temperatures and the thermocline- 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

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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.



#### Fig. 64. Representation of circulation speed of carbon in several parts of the land, surface layers of the ocean, deep ocean and seafloor sedimentscourtesy Phil Stoffer at Miracosta Education

The 'skin' at the top of the ocean comprises plant- and animal-driven processes that modulate 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, 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 dies, the food chain collapses, the oceans lose oxygen, and dead zones emerge. Cloud cover diminishes, sea ice and glaciers melt, more sun and inorganic  $CO_2$  enter 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, 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.

Farther down is a transitional zone in which temperature and salinity increase rapidly with depth. This transitional layer (the thermocline) is positionally stable, preventing mixing between the warm, upper layer from the increasingly deep, dark, pressurised, cold water that lies below. The transitional layer is not impermeable: the nutrient- and carbon-rich detritus of living organisms passively drops through the thermocline layer and settles on the seafloor. Most of this material simply stays there, but upwellings at the eastern boundaries of oceans and near the equator, and vertical mixing by the active movement of plankton and whales, bring a proportion of these nutrients up to the surface, causing photosynthetic plankton to proliferate and use solar energy to turn atmospheric carbon into nutrition for the entire marine food web.

Vertical mixing 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.

### **10.7 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 into 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 of 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 CO2 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.

#### **10.8 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 assimilates 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".
#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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.



Fig. 65. Life in the oceans, eg. Coccolithophores, plays a significant role in the flux of carbon, including its deposition at the bottom of the sea. – Plymouth Marine Biological Institute



Fig. 66. Plankton sequestrates considerable atmospheric CO<sub>2</sub>, 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 have now unbalanced the carbon cycle.

### **10.9 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 very bad, even critical condition. Around the world, we see more and more hypoxic and even complete dead zones.



## Fig. 67. 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.

### **10.10 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.

Moreover, ocean acidification can reduce the ocean's capacity to absorb CO<sub>2</sub>, accelerating the rate of global warming.



Fig. 68. pH changes over time - courtesy Goes Foundation.

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.

### **10.11 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 bringing 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.

### **10.12 CALL TO ACTION**

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

- 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.
- Protect and revive coastal ecosystems that serve as nurseries for life both on land and in the oceans. This includes the 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 expanding 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 ratelimiting 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 arounds 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, but 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 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. Preventing massive marine habitat destruction by strictly regulating deepsea 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, 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.

# Substantially Sequestering Atmospheric Carbon

### **11.1 WHERE IS ALL THE 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 tonne of atmospheric carbon in  $CO_2$  translates to 3,66 tonnes 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 tonnes of carbon per hectare per year, while temperate and boreal forests can sequester up to two to three tonnes 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 meters. 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% 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 underestimation. It is likely that both the open oceans and especially the coastal marine ecosystems 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.

### 11.2 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.

### **11.3 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 the 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.

### **11.4 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.



Fig. 69. 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.

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 and 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.

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.



# Fig. 70. From Natural climate solutions, where we can bury carbon and how much - courtesy PNAS

Meanwhile, the regeneration of those essential ecosystems, like tropical rainforests, will both renew and rejuvenate small water cycles and increase the safe storage of CO<sub>2</sub> in soils and biomass.

# 11.5 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 have the 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.

# Can We Slow and Reverse Sea Level Rise?

Sea level rise and fall have 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 if these changes happen fast. 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. There is a high likelihood that near-future sea level rise will accelerate and be measured in metres rather than centimetres. The current IPCC forecast of 1.1 metres by 2100 is a scenario that does not include the possibility of the 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 notso-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 thesis 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.

### 12.1 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.

In the figure below you can see the attribution to SLR from different sources,



Fig. 71. Global mean sea level (GMSL) contributions from the Antarctic ice sheet (AIS) (a), Greenland ice sheet (GrIS) (b), mountain glaciers (c), soil moisture (d), artificial reservoirs behind dams (e) and groundwater (f) in the period of 1993-2010. Note differences in the vertical scales. Courtesy Geophysical Research Letters

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 has 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.

### **12.2 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.



### Possible pathways for future sea level rise

### Fig. 72. Possible Pathways for future sea level rise. Courtesy NOAA, Sweet 1 foot = 304.8 mm, 7 feet = 2.13 metre

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 in Antarctica depends a lot on the rate of floating sea ice, which is retreating in 2023 at a much faster pace than expected. Here is the situation on 13 October 2023.



## Fig. 73. Antarctica Sea Ice Extent 2023. Courtesy National Snow and Ice Data Center, University of Colorado Boulder.

There are a number of consequences from SLR. The first and most obvious one is:

- Flooding 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

Bangladesh has 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.

### 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 a 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 Mitigating Action Along the Shore Lines: 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.



Fig. 74. Oyster bed on the rock under the sunlight – Photo Aiyoshi/Shutterstock

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, and 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, 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 biologies, such as kelp forests and seagrass 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.

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 naturebased 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 got there through precipitation, so 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 regard 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 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, and 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 quickly become a positive feedback loop. Some evidence comes from a record salmon run in Russia's rivers after the eruption of a volcano:

"Last spring Mother Nature sent towering clouds of rich volcanic ash into the North Pacific Ocean as Russian volcano Bezymianny erupted. The salmon are proof that ocean restoration with natural dust simply works."

Some people suggest considering engineering to grow ice, especially with regard 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 the 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 make 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 coastal erosion repair through smart measures like mangrove and coral reef protection and forms of engineering designed to intentionally increase the 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 community 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.

### **Reforming Global Food Production**

### Disclaimer

The Cooling Climate Chaos team does not have the expertise to offer detailed 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.

### **13.1 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 the industrialization of food production, while antibiotics and better hygiene increased longevity. But the story starts with the cultivation of grass seeds as a huge game changer in the development of our species and tangentially in changing climate change, 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 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 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, with the Nile on the west side, 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 were 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 these 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, facing 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 access to sufficient food for all at the top of our priority list.

Water is a 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 is 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 a rapid increase in 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.

# 13.2 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.

### 13.3 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 cannot eat mangoes in Europe year-round flown in by aeroplanes, but it also means that we cannot feed 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 CO2 would quickly facilitate this shift.

### 13.4 REDUCING ANIMALS IN OUR FOOD

This brings us to the second important key, we need to shift towards more plantbased 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 the 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.

### 13.5 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.

### 13.6 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, and 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, and 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.

### 13.7 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 the 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 substantially increases sustainable aquaculture in its coastal waters, it could get much closer to food sovereignty.

### 13.8 A FLY IN YOUR SOUP

While eating insects will give an itch to a lot of people, those small, rather offputting creatures are already a staple diet in many parts of the world. In Thailand, insects such as crickets, grasshoppers, and 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.

### **13.9 NATURAL FERTILIZERS**

While we described marine ecosystems and insects as two possible large solutions for making food more sustainable, and 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: fastgrowing 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 fertilizers in a circular agricultural system.* 

### 13.10 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 is threatening the beaches of the Caribbean. Once it starts rotting, the seaweed gives off pungent smells and causes irritated skin and eyes. If this seaweed makes a landing, that 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 is 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.

### 13.11 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.



Fig. 75. 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 (which 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.

### 13.12 LESS 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 for 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 is 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.

Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

### Part III: How We Can Solve the Climate Mess within Our Lifetime

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



Fig. 76. 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<sup>i</sup>*, 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<sup>ii</sup>*, 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*. 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.

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

<sup>&</sup>lt;sup>i</sup>https://www.donellameadows.org/wp-content/userfiles/Limits-to-Growth-digital-scan-version.pdf <sup>ii</sup>https://en.wikipedia.org/wiki/A\_Blueprint\_for\_Survival

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 everincreasing 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.



Fig. 77. Cover of the Game Changing 1972 Publication "The Limits To Growth"



Fig. 78. Dump trucks unloading garbage over vast landfill. Smoking industrial stacks in the 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 a 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 turn 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<sup>iii</sup> 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, which are themselves the result of a response to market forces. This cycle of competition and innovation then generates wealth, and 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 in Asia, it has done so in an unsustainable way and at the expense of the future. The current

<sup>&</sup>lt;sup>iii</sup>https://sdgs.un.org/goals

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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.



# Fig. 79. 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 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<sup>iv</sup>. In the book, he explores the stories that have shaped our world, particularly the narrative of separation that underpins much of modern civilization. Eisenstein encourages

<sup>&</sup>lt;sup>iv</sup>https://charleseisenstein.org/books/the-more-beautiful-world-our-hearts-know-is-possible/

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,"<sup>v</sup> 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 to the world. It is now, when the future 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 *manomaya*, 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 an 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

<sup>&</sup>lt;sup>v</sup>https://www.joannamacy.net/work

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."



Fig. 80. Joanna Macy. Photo by Adam Loften

Joanna explains that in these mythical times, the answer lies in our courage to face the danger and the 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.<sup>vi</sup>

Maybe the most radical of all is the author, Daniel Pinchbeck. In his book "2012: The Return of Quetzalcoatl"<sup>vii</sup>, 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.

<sup>&</sup>lt;sup>vi</sup>https://www.youtube.com/watch?v=z6TM8g2YNDo The Shambala Warrior Prophecy with Joanna Macy on YouTube.

viiISBN 10: 1585425923 / ISBN 13: 9781585425921, Published by Penguin, 2007
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 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 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 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 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 to generate 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 of 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 creating this new future of simple abundance and care as part of a living planet looking for new challenges in 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 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 ground breaking legislation recognizing the Whanganui River, a river of great significance to the indigenous Māori people, as a legal person<sup>viii</sup>. 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

<sup>&</sup>lt;sup>viii</sup>https://www.parliament.nz/en/get-involved/features/innovative-bill-protects-whanganui-river-with-legalpersonhood/

sounds strange, we need to remember that legal personhood has been established for institutions and companies for many centuries, so why not apply this to 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.



Fig. 81. Maori 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<sup>ix</sup>, sketches a good way to limit

<sup>&</sup>lt;sup>ix</sup>https://www.nature.com/articles/s41586-023-06083-8

the use of the planet's resources so that they are used sustainably. It states that our planet's health and human well-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 make 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, needs to happen everywhere. By such means, people everywhere should be able to declare their lands, rivers, watersheds, mountains, forests, and 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<sup>x</sup>, 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<sup>xi</sup> 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 unlawful or wanton acts committed with the knowledge that there is a substantial likelihood of severe and widespread or long-term damage to the environment being caused by those acts.



Fig. 82. Stop Ecocide movement – design courtesy Squiff Creative Media

<sup>\*</sup>https://ecocidelaw.com/

xihttps://en.wikipedia.org/wiki/Rome\_Statute#

**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. The 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 caring 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's 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 17<sup>th</sup> 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.<sup>xii</sup> 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 sharp

<sup>&</sup>lt;sup>xii</sup>Francis Bacon, Novum Organum. Published in 1620

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 feedback, 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 in the slum of materialism," he observed with bitter irony.<sup>xiii</sup>

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.

Once agriculture got underway, settlements became larger and the size of social groups surpassed the so-called "Dunbar number"xiv, 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.

x<sup>iii</sup>Siegfried Giedion's book Mechanization Takes Command: A Contribution to Anonymous History, published in 1948.

<sup>.</sup>xivhttps://en.wikipedia.org/wiki/Dunbar%27s\_number

Surpassing the Dunbar number also introduced what is known as the Tragedy of the Commons<sup>xv</sup>, 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.

**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 rare earth needed to make a computer chip work.

In this context, a new asset class is proposed: productive, biodiverse, climateresilient 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 eco-services, such as carbon credits on top of the other benefits, make an 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 appeals to a wide array of investors. They are also bound through their bylaws to only invest in investment-grade investments as set by the international rating agencies.<sup>xvi</sup>

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

<sup>&</sup>lt;sup>xv</sup>https://en.wikipedia.org/wiki/Tragedy\_of\_the\_commons

xvihttps://www.investopedia.com/ask/answers/what-does-investment-grade-mean/

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 regulations such as that which the EU is rolling out with its corporate sustainability reporting directive (CSRD)<sup>xvii</sup>, 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<sup>xviii</sup> 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 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 the regeneration of the planet and the transition to regenerative food production, circular production of goods and so on.

Accelerating this wave of institutional investment and 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

xviihttps://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-andauditing/company-reporting/corporate-sustainability-reporting\_en

<sup>&</sup>lt;sup>xviii</sup>https://en.wikipedia.org/wiki/Taxonomy

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 the creation of an Ecological Benefits Framework (EBF) that can help in aligning the taxonomy and valuation of eco-services 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, incentivizing 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.

On mobile devices, purchasers—or in the case of public companies, shareholders—can now have a "baseball card" like a 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.



Fig. 83. Digital Representation Measured Natural Assets and Ecoservices – Courtesy Ecological Benefit Framework Group

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 capitalization of all global stock and bond markets is 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 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 a 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, 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 normabiding 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.

It may seem that we have drifted a long way from exploring ways to redesign finance to regenerate the planetary biosphere. Nevertheless, this exploration of how we must organise ourselves in a way that we can move to **sustainable stewardship of the Earth** in the same way it is natural for parents to take care of their kids. We must protect the sacred vitality of nature upon which our survival and well-being depend. 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, and 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.

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.

1. Token-based Membership	5. Graduated Stakes for Rule Violations	
2. Rules determined via Blockchain Governance	6. Challenge Response Game for Dispute Resolution	
3. Proposal System for Members	7. Censorship Resistance through Decentralization	
4. Machine Learning & Monitoring	8. Hierarchical Nested Contracts	

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~	Design	•••	ostioni	Contracto

Fig. 84. Source: David Dao, 2018 Decentralized Sustainabilityxix

xix https://medium.com/gainforest/decentralized-sustainability-9a53223d3001

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 programme."

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 the 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 Al can organize for us. This combined with the extraordinary scope of search engines and 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 a global voluntary-participation distributed techno-social network to regenerate the biology of the planet and simultaneously strive for social cohesion and 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<sup>xx</sup>, which featured four especially 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 Inter-operability: 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 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 for 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

xx https://en.wikipedia.org/wiki/Internet\_governance

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 on 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 the 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<sup>xxi</sup> and we would need to invest in the 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.<sup>xxii</sup> If the world will pay for carbon sequestration at a rate of around 50 USD per ton and

<sup>&</sup>lt;sup>xxi</sup> https://wedocs.unep.org/bitstream/handle/20.500.11822/37919/NatureG20.pdf <sup>xxii</sup>https://medcraveonline.com/IJBSBE/IJBSBE-09-00237.pdf

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<sup>xxiii</sup>, 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 create tangible, tradeable assets for investors to contribute to environmental conservation while earning a return on their investment and a great chance to appreciate 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 derisked 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 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 loans 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

xxiiihttps://en.wikipedia.org/wiki/Robin\_Hood\_tax

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 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 shortterm gain over long-term sustainability. This has resulted in unprecedented environmental degradation, climate change, and loss of biodiversity, putting the future of 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.

Onward! Because we are running out of time!

#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

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#### Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years



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## INDEX

#### Α

amazon basin, 22, 58–59, 61–65, 67–72, 76–77, 79–82, 84–86, 88–90, 92, 94, 96–98, 100, 102, 110–111, 154, 173 Anthropocentric emissions, 2 Atmosphere, 1, 5, 10, 13–16, 18–20, 28–29, 31, 33–38, 40–46, 48, 50, 52–53, 56–57, 69–73, 78, 80–82, 84–86, 92, 94, 96–97, 100, 105, 109, 112–113, 115–116, 126–128, 130–135, 140–142, 149–150, 165, 169, 174 Atmospheric carbon, 30, 82, 96, 101, 127, 131, 136, 139–140

### В

Biosphere, 4–5, 10, 13, 15, 23, 44, 48, 57, 69, 78, 124, 151, 166, 169–170, 179–180

### С

capacity-building support, 56 Carbon credit, 10, 183 Climate chaos, 1–186 Climate recovery, 118 Cosmology, 26 Cumulo-nimbus clouds, 20, 91

## D

Deforestation, 14, 21, 34, 62–63, 66–70, 75–77, 79–80, 82, 90, 92, 96, 102, 107, 110–111, 113, 121–122, 140, 154, 157, 161

### Е

Ecological benefits framework, 177 Ecorestoration alliance, 2 Ecosystem rehabilitation, 6 Environmental conservation, 6, 183 Evaporative force, 70, 73–77, 80 Extraterrestrial powers, 167

## F

Fossil fuels, 18, 22, 34–35, 46, 52, 55, 83, 93, 124, 134, 139–140, 153–155, 160–161

### G

Global warming, 2, 41–42, 54–55, 57–58, 61, 70, 76–77, 92–93, 108, 132, 135, 140–141, 144, 155 Greenhouse gas, 18–21, 28, 38, 40, 42, 53, 56–57, 76, 84, 92–93, 128, 142, 155, 165 Greenhouse gas blanket., 19

## н

Horrendous mudslides, 56

### Κ

Kyoto Protocol, 56, 70

### L

Lunar energy, 36

Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years Index

#### 0

Ocean acidification, 135, 141, 150–151 Open ocean, 128–129

#### Ρ

Photosynthesising-vegetation, 19 Phytoplankton, 11, 19, 21, 46–47, 67, 124–125, 128, 130, 132–133, 137, 141, 150– 152 Planetary science, 13

S Salinization, 20 Savannisation, 68 Solar wind, 14, 30–31 Syntropic farming, 25

# т

Thermonuclear reaction, 28

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