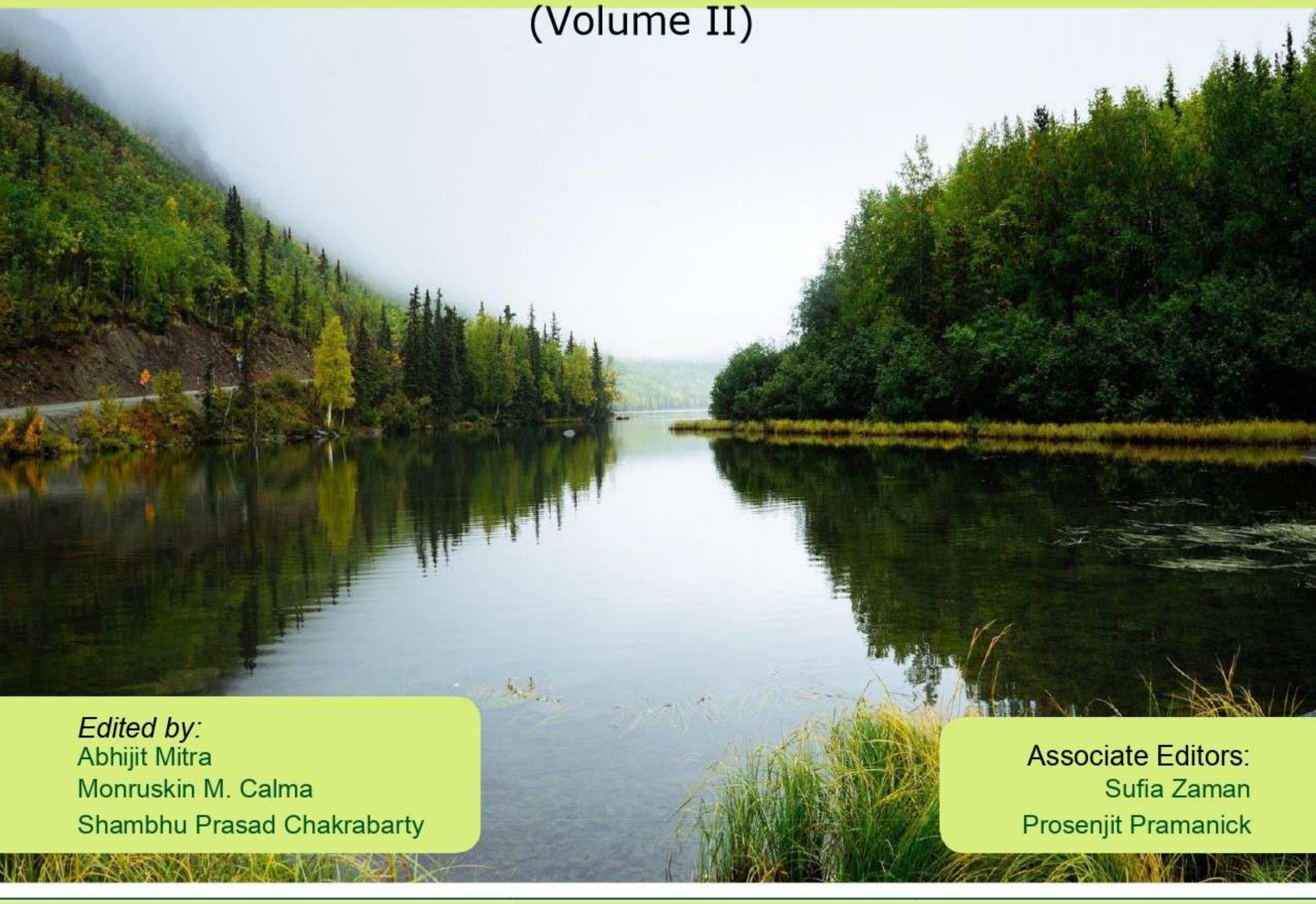
NATURAL RESOURCES AND THEIR ECOSYSTEM SERVICES

(Volume II)



Edited by:
Abhijit Mitra
Monruskin M. Calma
Shambhu Prasad Chakrabarty

Associate Editors:
Sufia Zaman
Prosenjit Pramanick

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ASSOCIATE EDITORS

Dr. Sufia Zaman
Dr. Prosenjit Pramanick

H.S.R.A PUBLICATIONS
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Ph: 7892793054
Email: hsrapublications@gmail.com
www.hsrapublications.com

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CHAPTER 1

Flattening the CO_2 curve and stabilizing climate for human sustainability by regenerating biodiversity, biomass, soil fertility, and ecosystem services

Thomas J. F. Goreau
Global Coral Reef Alliance, 37 Pleasant Street, Cambridge, MA 02139, USA

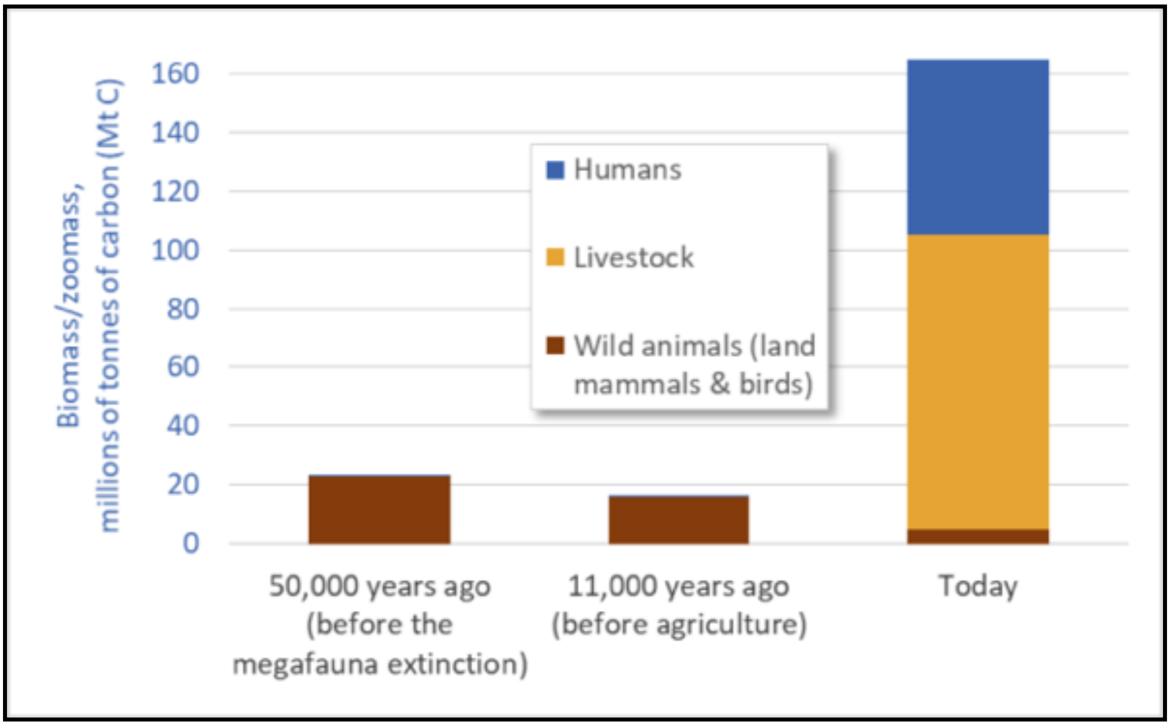
Native American proverb: "When the last tree is cut down, the last fish caught, the last river poisoned, only then will you realize that you cannot eat money".

Introduction: Flattening the CO_2 curve for human sustainability

2020 will be remembered for the Covid epidemic, which set global sustainable development back by decades. It could have been much worse had not most countries taken science-based measures to flatten the Covid infection curve and prevent collapse of the health system. 2021 must be the year the world starts scientifically-sound policies to seriously flatten the CO_2 curve to prevent collapse of our planetary environmental life-support system and the extinction of coral reef ecosystems (Goreau, 2020).

The origin of Covid, the worst human epidemic for a century, lies in the human-caused collapse of global biomass, biodiversity, and ecosystem services. The root conditions for Covid spread come from the fact that humans, and the animals we keep (cattle, sheep, goats, pigs, chickens, ducks, etc.), now greatly outweigh all other animal species. As the unavoidable result, we and our animals are now the preferred target for pathogenic diseases, which evolve many times faster than we can, requiring more complicated and expensive vaccines. Covid is NOT "the big one", which will inevitably come, because even though Covid is very infective, it is not very effective, killing only around 3% of its victims. The stage is set for more frequent and deadlier pandemics in the future that might kill almost all their victims, like the worst plagues of the past (Wallace, 2016).

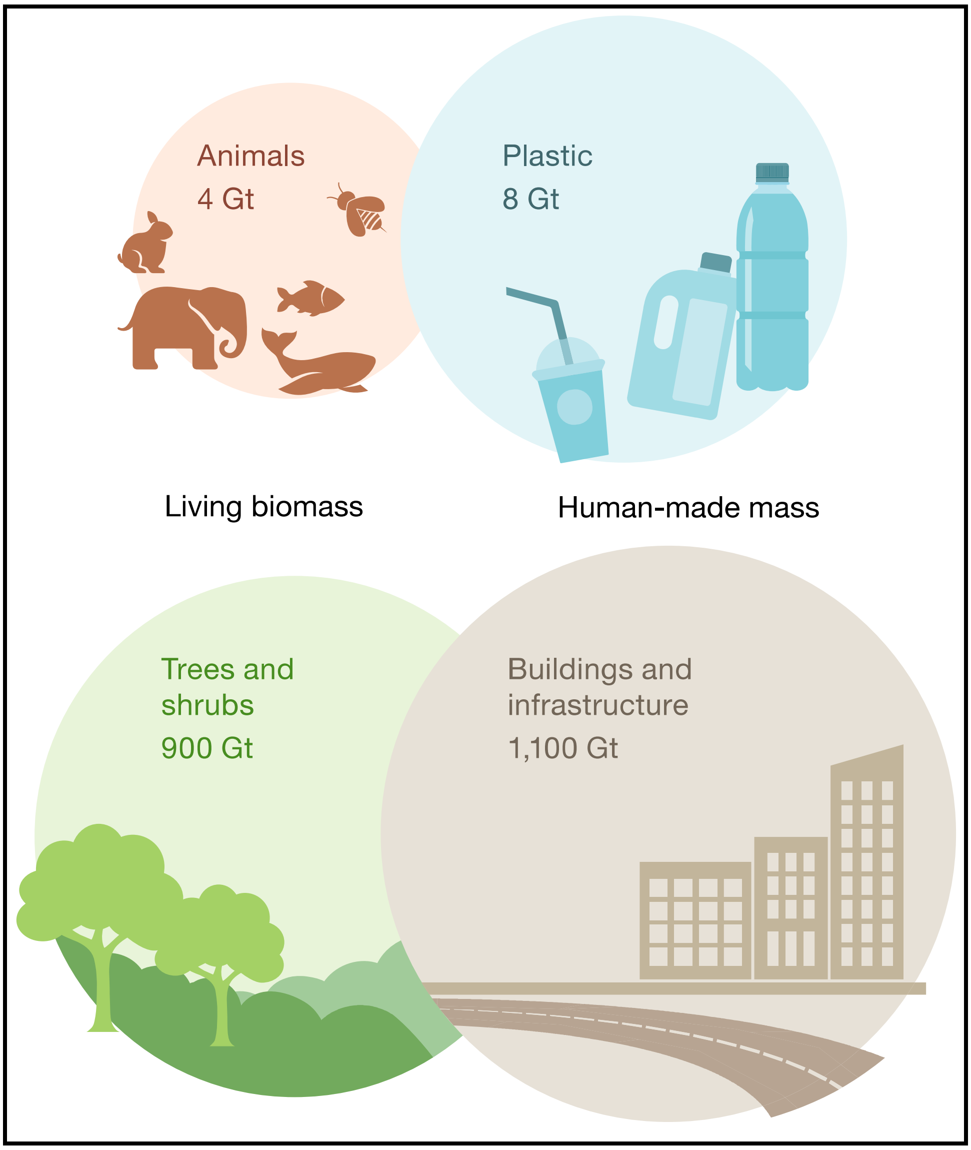
Our leaders have not learned from history, and only hope to get back as fast as possible to the old unsustainable economy, based on destruction of natural resources using polluting fossil fuels, without thought of future human sustainability. Here strategies to resuscicate our collapsing natural planetary life-support systems are outlined that could be widely applied in India and all countries to flatten the CO_2 curve for long-term sustainability. They use BioGeoTherapy, or regenerative development to reverse climate change, maximizing biomass, soil carbon, biodiversity, and ecosystem services to stabilize climate.



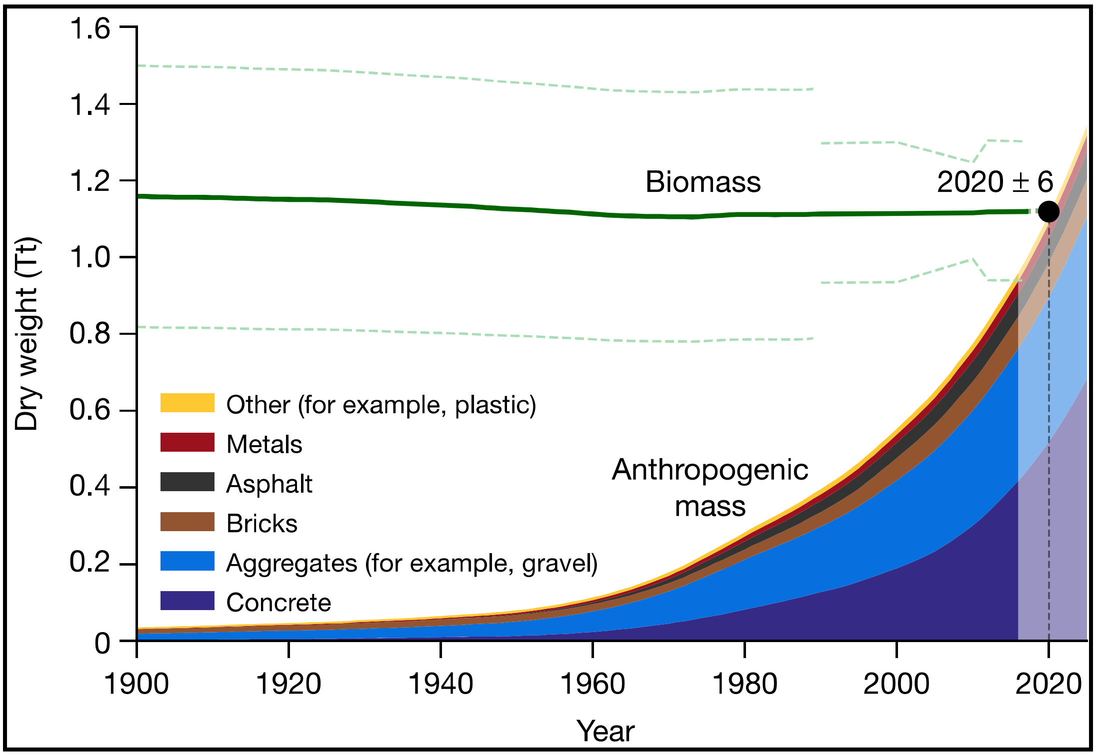
Animal Biomass was reduced by half by human hunting before the development of agriculture 11,000 years ago. Since then humans and our domestic animals vastly outweigh all wildlife. https://www.darrinqualman.com/humans-livestock-extinctions/

2020: The year human construction outweighs natural biomass

2020 marked yet another irreversible change in the planet caused by human demography, the year that human constructions (anthromass) outweighs all the world's dry biomass (Elhacham et al., 2020). The weight of plastics alone is now twice the weight of all living animals, and the weight of human constructions (concrete, gravel, sand, bricks, asphalt, steel, etc.) now exceeds the dry weight of all the plants on earth, and is rising exponentially, while forests are vanishing. It is important to note that these estimates of human construction do not include buildings made of wood, nor the massive amount of earth moving construction for dams, sea walls, drainage, dredging, land filling, etc. (Elhacham et al., 2020).

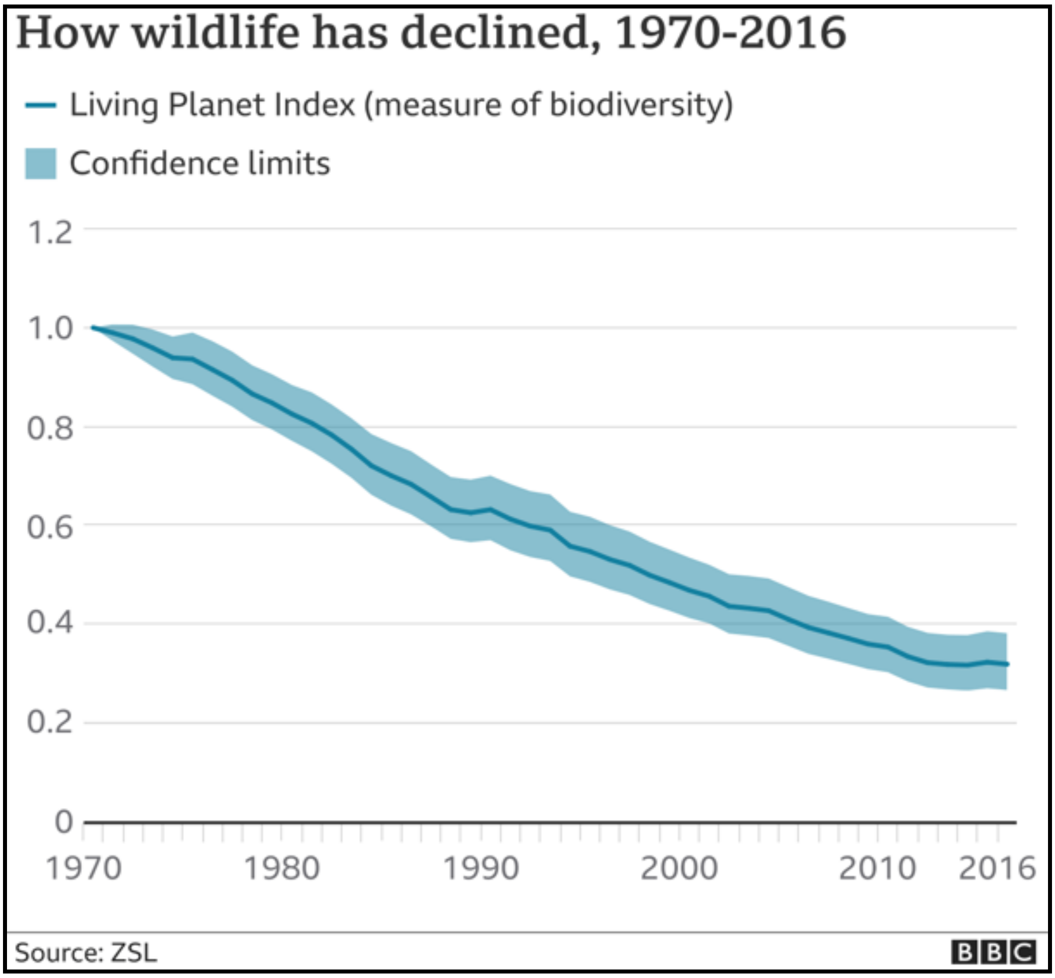


Global Anthromass exceeds Biomass. Elhacham et al. 2020

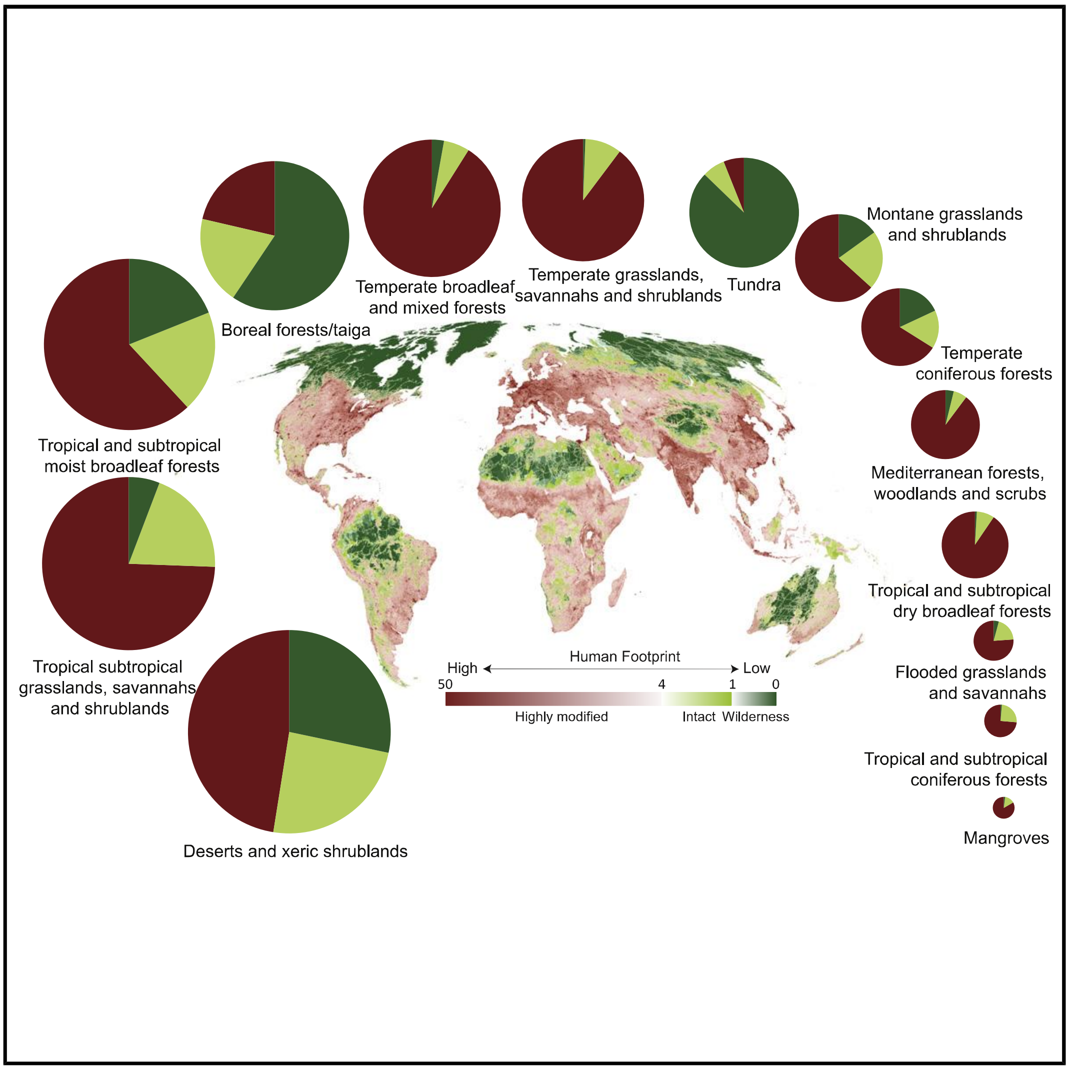


Anthromass is increasing exponentially, while Biomass is decreasing. Elhacham et al., 2020

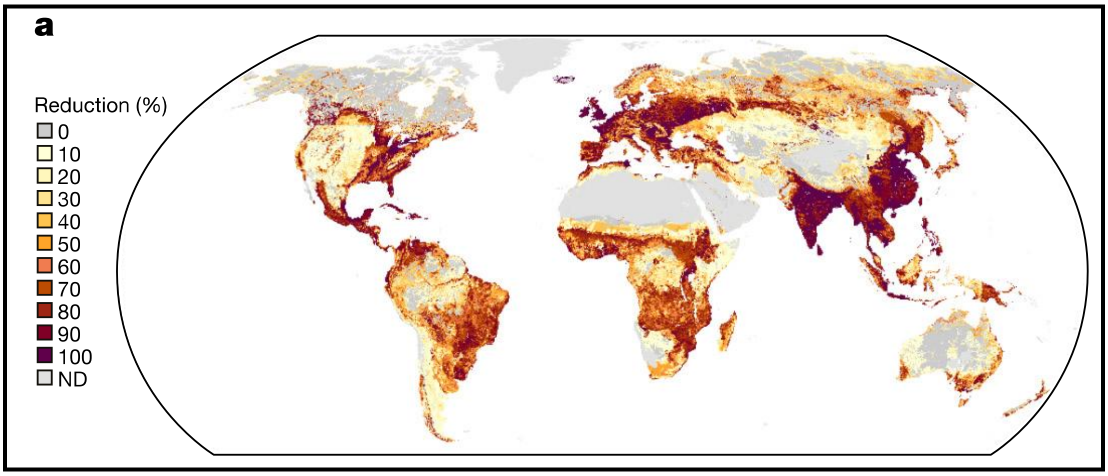
Most humans now live in cities, and many are entirely surrounded by artificial construction, with no signs of green nature except in tiny artificial parks. No wonder they have little or no grasp of how nature provides and cleans the air they breathe, the water they drink, the food that they eat, and regulates their climate at safe levels. Nor do our schools teach us how to maintain a safe environment for the future.



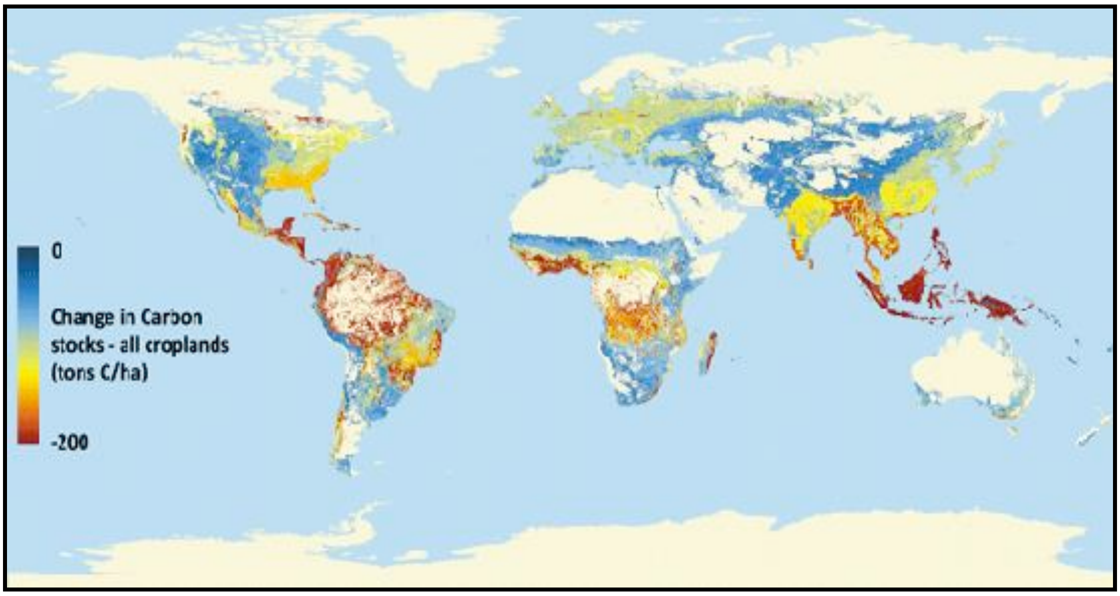
In the last 50 years we have lost two thirds of wild animals.
https://www.bbc.com/news/science-environment-54091048



Between 2000 and 2013, Earth lost an area of undisturbed ecosystems roughly the size of Mexico (Williams et al., 2020). Every ecosystem was affected.



Reduction of original biomass by humans. Much of India, China, and Europe have lost more than 90% of their biomass. Erb et al., 2017.



Losses in cropland carbon, largely soil. West et al. 2010

False economics of Ecosystem services

Since our economic and political systems value quantity of money and not quality of life, we have created doubly false economics to rationalize increasing destruction of Nature's essential life support services.

First, we do not pay to maintain Nature's vital services that safely stabilize our planet's atmospheric composition, temperature, sea level, water, food, and soil, we treat these as free goods worth only what we pay for them: nothing at all.

Second, every gram of our artificial world incurs a global ecological debt, consuming non-renewable resources, adding CO_2, heat, and other pollutants to our climate system that we refuse to pay to clean up, an increasing burden that vanishing Nature can no longer handle.

Manhattan, 1609 and 2009. How much nature is needed to clean up our wastes? Illustration from "Mannahatta"; photograph by Yann Arthus-Bertrand/Corbis

We need to urgently bring real economics into balance by making our (unpaid) ecological debts pay for our (unpaid) ecosystem services, making the polluter pay the damages, taxing "bads", like CO_2 emissions, to pay for "goods", like CO_2 storage. Anything less is just fooling ourselves. Nature works by intensely recycling carbon, energy, water, and nutrients to maximal effect in cycles that we have stupidly broken because our greed exceeds our wisdom. This is not due to ignorance, the knowledge was always there, but policy makers refuse to listen to the facts or the science because it violates their political or religiously indoctrinated prejudices and convenient fables.

False climate goals: pre-Industrial CO_2 target needed, not Net Zero

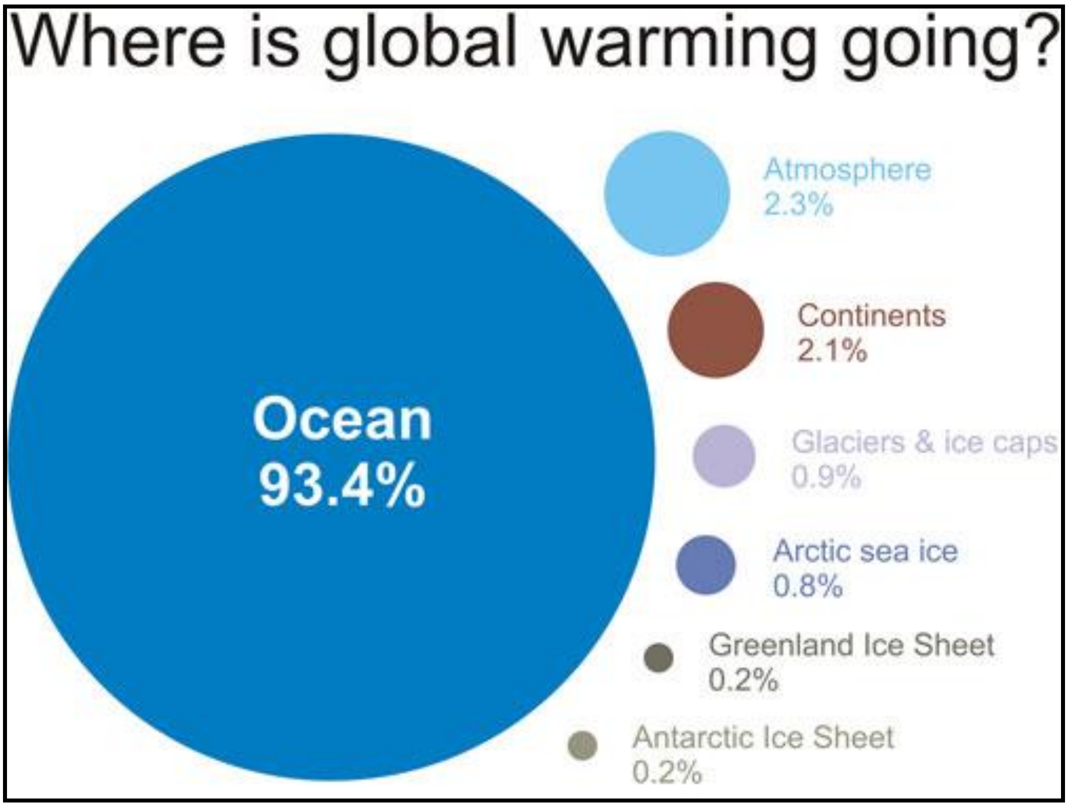
False monetary accounting of environmental costs and benefits is matched by false accounting of CO_2 sources and sinks, aided by adoption of false targets. If an accountant confused net and gross income of their client's money the way governments do with carbon, they should be instantly disbarred. False accounting and false climate targets were baked into the UN Framework Convention on Climate Change at the start.

When the first draft of the UN Framework Convention on Climate Change (UNFCCC) was sent to me in 1989 for review, as Senior Scientific Affairs Officer for global climate change and biodiversity at the United Nations Centre for Science and Technology for Development, I inserted many phrases aimed to make the draft both scientifically sound and complete so that it could meet its own goal of preventing serious alteration of the climate system. In particular I added complete global accounting of ALL greenhouse gas (GHG) sources and sinks, a Pre-Industrial CO_2 target, and explicit goals to protect Earth's most climatically sensitive ecosystems. All of these were promptly removed from the UN draft by governments, who wanted to account only for their own national fossil fuel emissions, and were eager to pass the blame, and the bill, to anyone else. The result is a treaty based on false accounting of carbon, with a vague goal that cannot be achieved by the measures proposed.

Everyone is now familiar with the alleged "scientific" "consensus" that 350 parts per million of CO_2 in the atmosphere (we are now at nearly 420 ppm) and 2 degrees C warming is "safe", and 1.5 degrees is "safer", but they don't tell you that these rises are only to the end of this century, and temperature will keep rising for thousands of years more, to uninhabitable levels for humans, and stay there for hundreds of thousands of years until the carbon is eventually stored away in marine sediments. Very few politicians understand that the standard IPCC projection is for short-term climate impacts only, and ignores more than 90% of the inevitable long-term changes that will continue to pile on, and on, afterwards. They don't realize that the InterGovernmental Panel on Climate Change (IPCC) was given a political mandate to present only short-term estimates and ignore the long-term ones, which politicians did not want to hear about. The least common denominator result is a UN Climate treaty that is death sentence for coral reefs, and a suicide pact for low lying countries, unless it is modified to be scientifically-sound. Vast carbon sinks are routinely claimed that are in reality minute, ephemeral, or fictitious and a whole industry has been built around bogus claims of "mitigation" and "offsets".

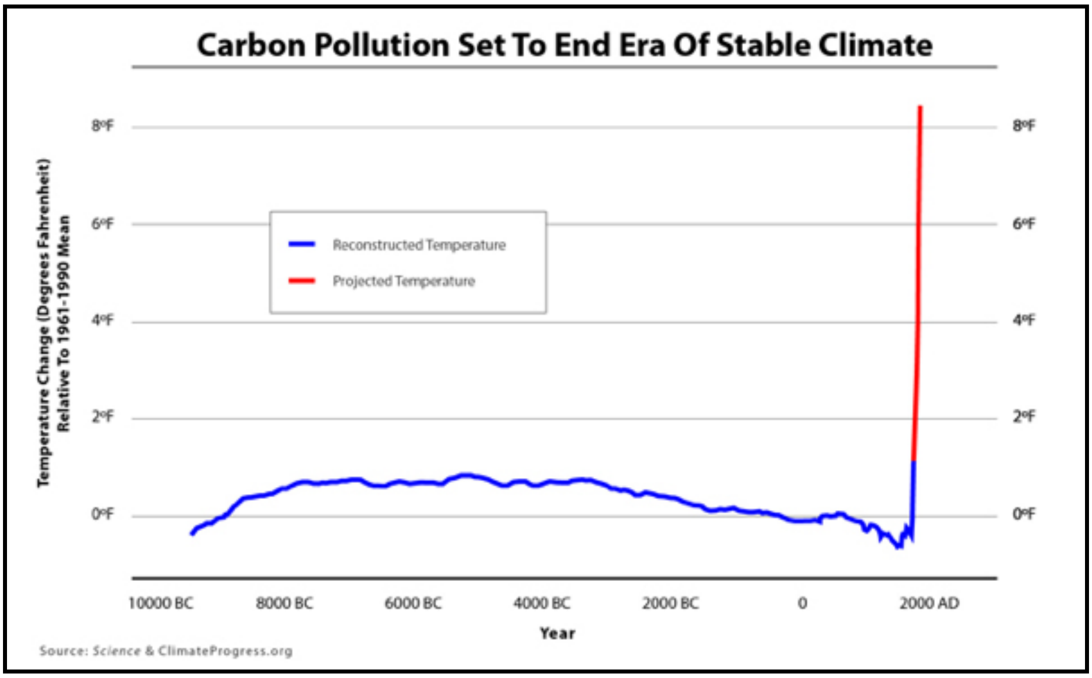
IPCCC Long-Term projections

It is easy to understand the fallacy of the climate change projections governments rely on, because when we increase GHGs in the air now, 93% of the heat trapped by the Earth vanishes into the ocean, which takes 1,500 years to mix. Since the deep ocean is at refrigerator temperatures, it will take thousands of years before we feel the full effect of warming from the CO_2 we add now. This is not included in IPCC projections as a result of what can only be described as dishonest politically-motivated smoke and mirrors. If all the heat that is being absorbed by the ocean had gone into the atmosphere instead, air temperature would have already risen by 36 degrees C (Whitmarsh et al., 2015)!



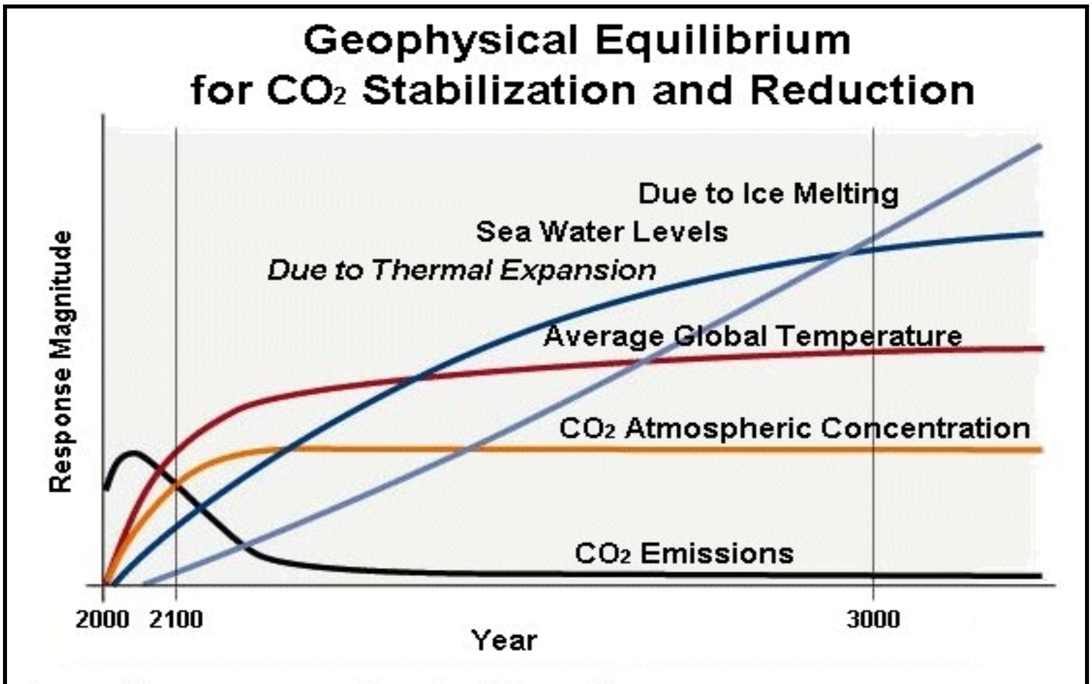
Where global warming goes. IPCC

We can see the global long-term impacts of CO_2 on temperature and sea level for millions of years more clearly on the North Coast of my home island, Jamaica, than anywhere on earth. Ancient sea level caves carved into the limestone cliffs should be preserved as UNESCO World Heritage Sites for Global Climate Change. They formed the last time when global temperatures were around 1-2 degrees warmer than today, and sea levels were around 7 meters higher than now. Hippopotamuses and crocodiles roamed the swamps where London, England now stands. The huge coral reefs that grew in front of this cave seem to have been killed by high temperatures and then flattened by immense waves from super-hurricanes or tsunamis. At that time CO_2 in the atmosphere was then only around 270 ppm, similar to what it was during the 10,000 years of stable climate that we disrupted with CO_2 after the fossil fuel driven industrial revolution. This is the goal we must seek for a temperature and sea level similar to that we have experienced since agriculture began (Marcott et al., 2013). Once the planet warms up for 400 ppm, sea level will be around 23 meters higher, and temperatures about 17 degrees C higher, similar to what it was before the Ice Ages began, and if we continue to use fossil fuels, we will face up to 70 meters of sea level rise (Rohling, 2019). Cockroaches will survive, but coral reefs can't, and humans probably won't. To reverse these changes the global climate data shows we need to reduce atmospheric CO_2 to around 270 parts per million.



Climate has been stable since the start of agriculture, but it is about to change dramatically. Marcott et al., 2013.

We need to face up to these long-term effects and stop deluding ourselves that they do not need to be reversed immediately, before damages become insufferable and irreparable.

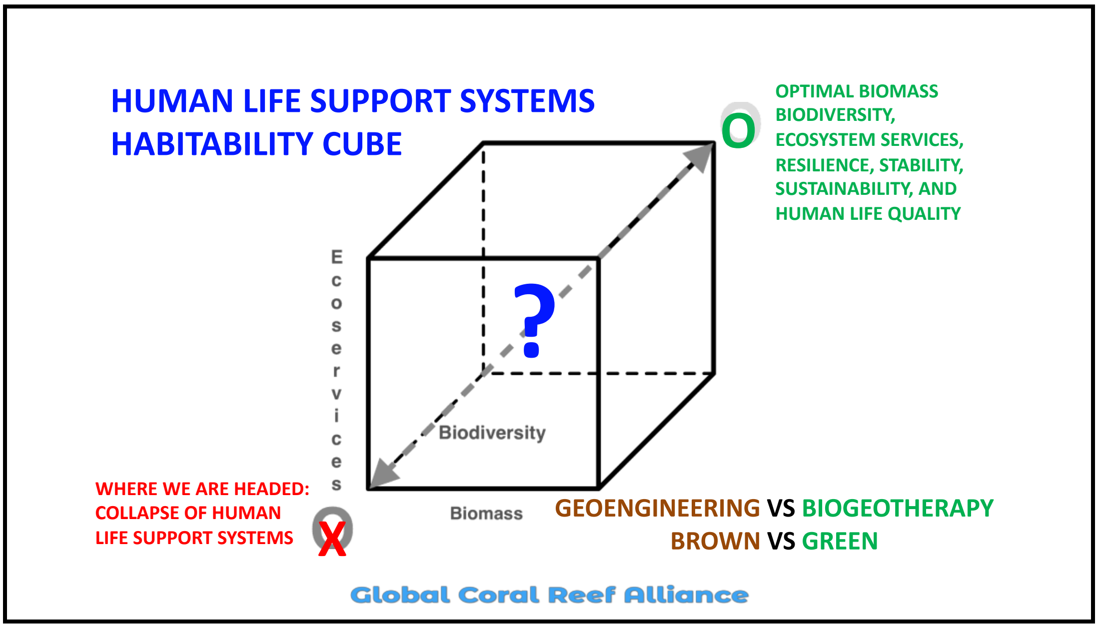


Source: Intergovernmental Panel on Climate Change

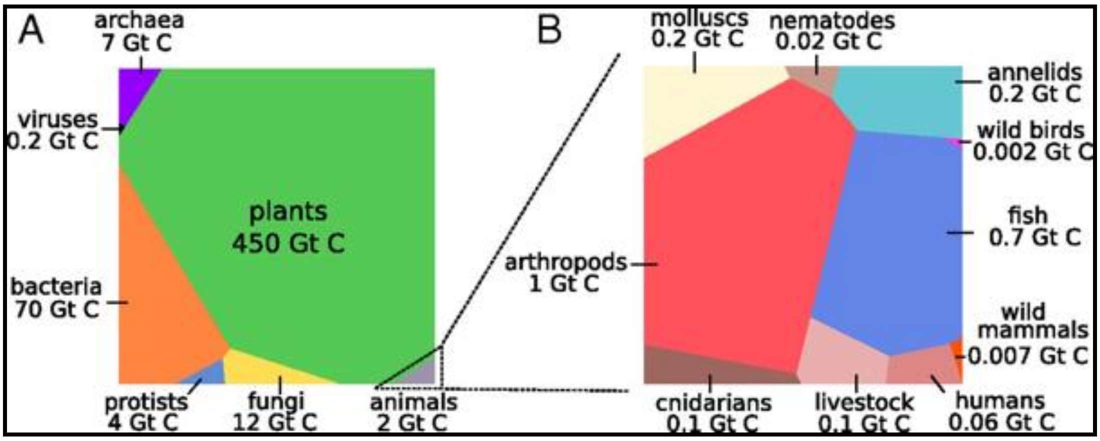
IPCC projections to policymakers and the public only give the short-term response and ignore the long-term responses because their scientific mandate was over-ridden by their political mandate. But the scientific community is very aware that this seriously underestimates what will happen in the long run. Notice that even after fossil fuel emissions go to zero, temperature and CO_2 remain high afterwards, and sea level rise from ice melting is still increasing a thousand years later!

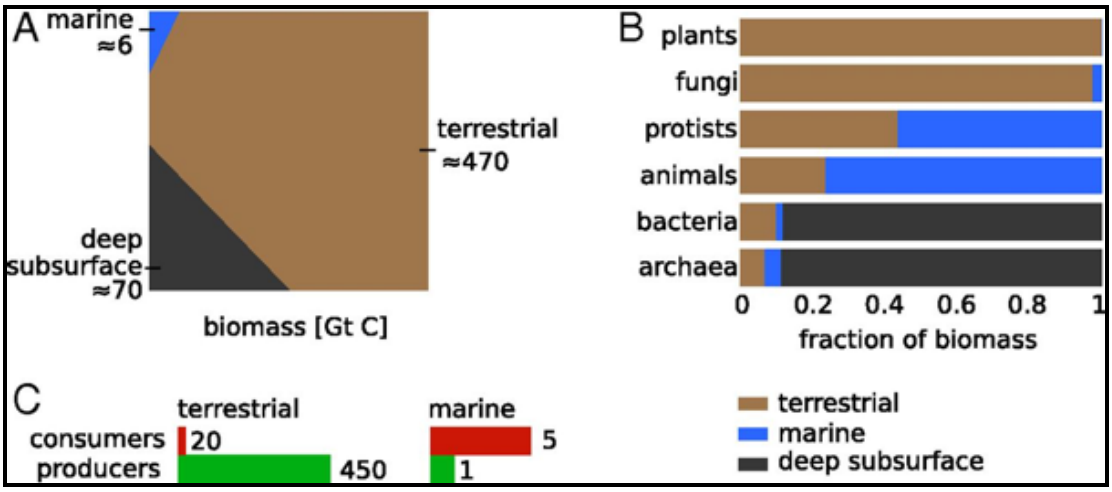
Three axes of long-term human sustainability

We can look at the long-term sustainability of humanity on earth as function of the three critical natural parameters, biomass, biodiversity, and ecosystem services. We are somewhere inside the habitability cube, shown by the question mark. At the moment we are on a degenerative trajectory, heading for the bottom left corner, with biomass, biodiversity, and ecosystem services being destroyed at increasing rates, while ecosystem debt rises exponentially. Vanishing natural ecosystems can no longer make up for the wastes from the anthromass that exceeds it.

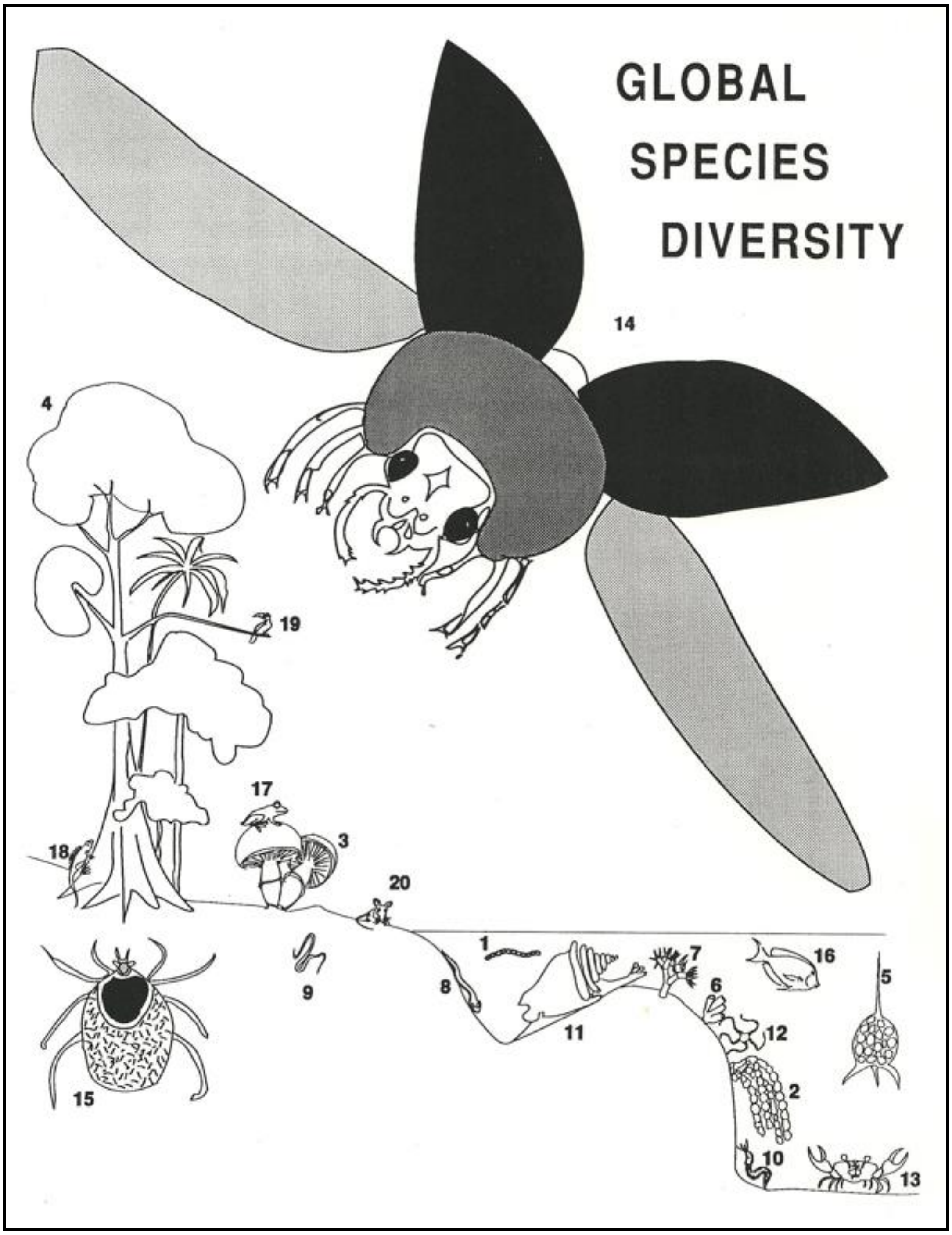


Our planet's life support systems are based on three fundamental axes, biomass, biodiversity, and ecosystem services. We are now racing towards the lower left corner, ecosystem collapse, when we need to move to the upper right corner of maximum sustainability.





Global Biomass classified by type of organisms (A & B, top row), by habitat (A & B, middle row), and trophic level (C, bottom row). Bar-On et al., 2018



Global Biodiversity. Drawing by Dr. Peter Goreau. Each major group of life is numbered according to its evolutionary sequence, and the size is proportional to the number of species. There are more insect species than everything else combined, but without the plants they would have no habitat or food, and without fungi decomposing dead plants the whole biological cycle would soon grind to a halt. Interconnections between species stabilize the entire system against severe perturbations.

Astonishingly, many schemes are being promoted to speed the race to the bottom by entirely replacing natural cycle climate regulation with physics and engineering schemes that will need vast amounts of energy, are extremely expensive, still unproven to work efficiently, and may cause worse problems than they solve. Widely called GeoEngineering, they include such proposals as huge outer space mirrors to reflect sunlight, shooting sulfuric acid rockets into the upper atmosphere, and machines that claim to chemically concentrate CO_2 from fossil fuel exhaust, using very strong alkali solvents, from which it must be extracted, in order to purify and concentrate it, and then pump it into holes in the ground, casing earthquakes and potential large uncontrolled releases to the atmosphere. These schemes aim to push us to the bottom left corner of an artificial world with minimal biomass, biodiversity, and natural life support systems, the equivalent of life permanently intubated on a respirator after terminal constipation.

A deceptive version of GeoEngineering, called Biomass Energy with Carbon Capture and Sequestration (BECCS), perversely posing as a “green” solution, is the current favorite of countries that have cut down their forests and of the big industrial/chemical agriculture industry. BECCS envisions vast forests of identical tree clones, cut and burned in large central power plants, where CO_2 is purified and pumped into the ground. Huge profits are envisioned by its proponents, mostly from carbon credits, but the soil will be quickly stripped of nutrients, productivity will plummet in each cycle, biodiversity will be destroyed, soil will be eroded, and the trees will be very vulnerable to diseases, pests, and forest fires that spread uncontrolled. Worse, it removes the raw material of life from being recycled into more useful biological forms.

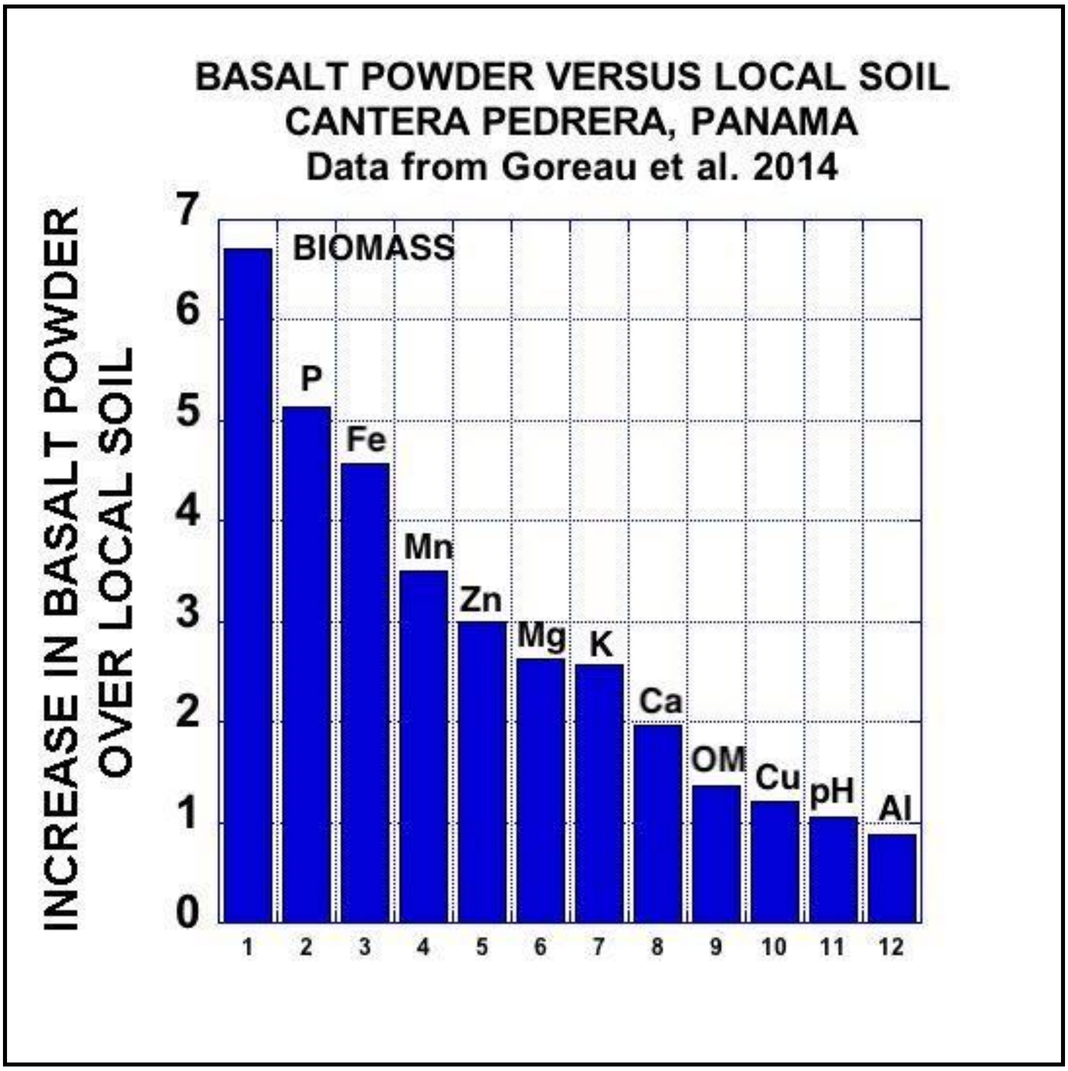
Global warming is greatly accelerating biomass destruction. Record high temperatures in 2020 triggered record forest fires all across the world, across South America, Australia, North America, and Asia, including Arctic tundra. The CO_2 released dwarfed fossil fuel emissions in many places. Record high temperatures in the Arctic during 2020 wiped out the last old multi-year floating ice, the vanishing remnant is now all thin first-year ice, and when it melts away in summer global warming will greatly accelerate (Wadhams, 2017). Forest fires and ice cap melt are two of the strongest positive feedbacks on climate that increase global warming, but neither is currently included in IPCC models of climate change!

Regenerative and degenerative carbon cycles

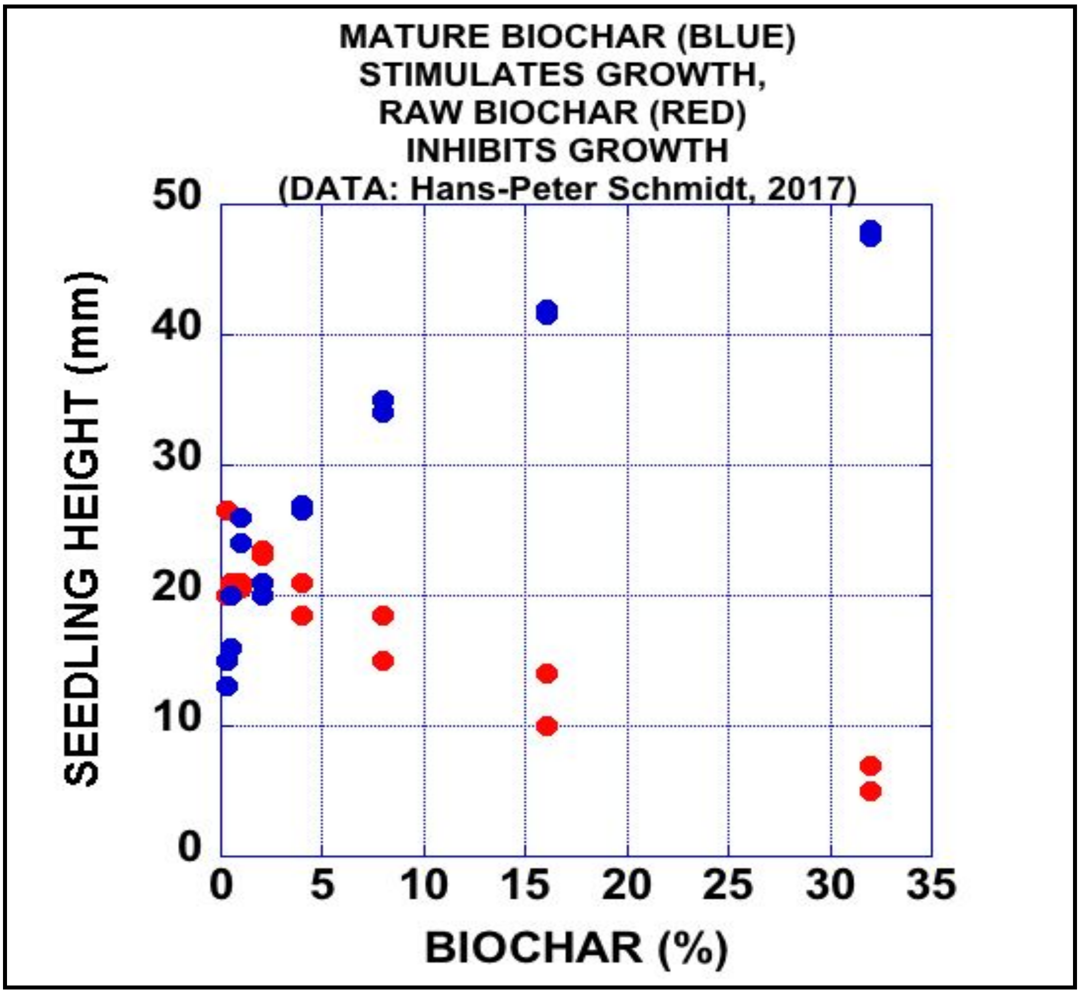
Regenerative strategies, or BioGeoTherapy, moving to the upper right corner of the habitability cube by maximizing biomass, biodiversity, and ecosystem services, are the antithesis of degenerative strategies and aim for a stable, sustainable, safe climate whose biosphere regulates itself again.

Regenerative land use strategies have been developed in every continent except Antarctica, for every climate, soil type, ecosystem, and crop by people who worked out from their own experience how to maximize intense internal recycling of carbon, water, nutrients, and energy within complex ecosystems with minimal input (Goreau, Larson, & Campe, 2014). This is how coral reefs and tropical rain forests naturally functioned until we destroyed most of them.

Regenerative land management rebalances the global carbon cycle form destruction back to production (Goreau 1987; 1990), increasing biomass and ecosystem services by greatly enhancing soil fertility through rock powder remineralization and biochar. Both of these materials act best together (Goreau, 2020) as natural, long-lasting, slow-release fertilizers, lasting for hundreds to thousands of years, increasing biological production by greatly improving water and nutrient holding capacity of soils, and increasing growing season length. Furthermore, increased transpiration by trees cools the land surface and increases rainfall.



Increase in biomass production and essential soil nutrients in Panama for trees growing in basalt powder from a quarry versus impoverished nearby soils. No Biochar or fertilizer was used. Data from Goreau, 2014.

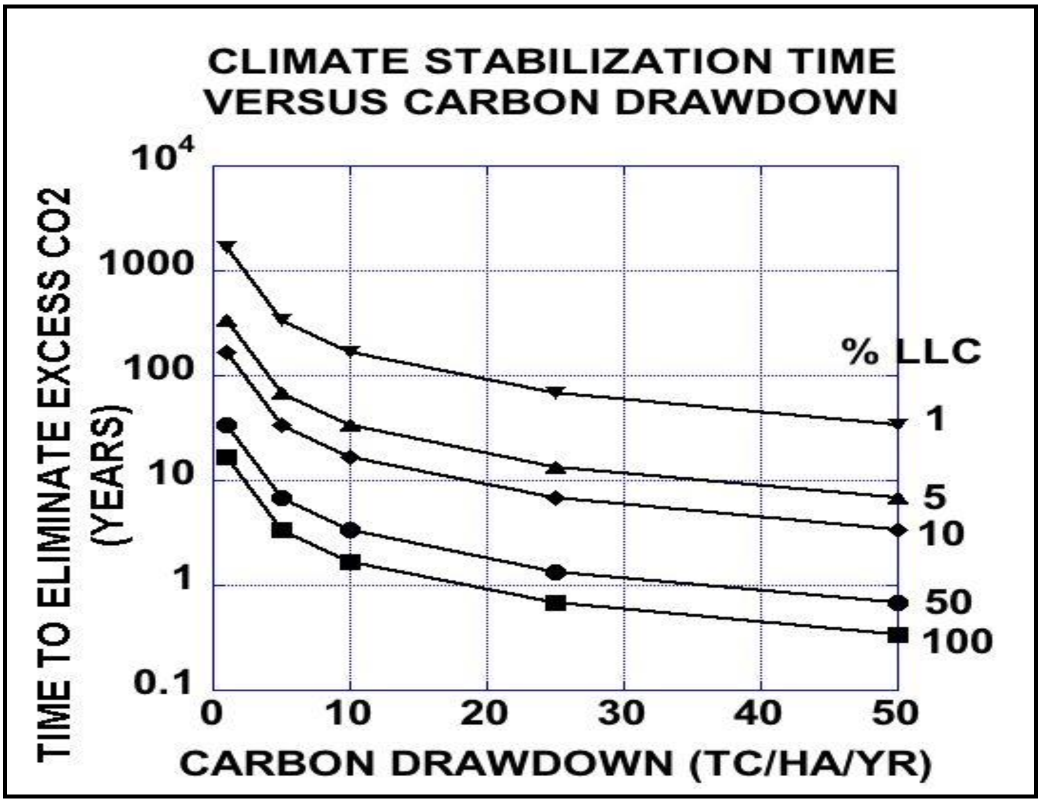


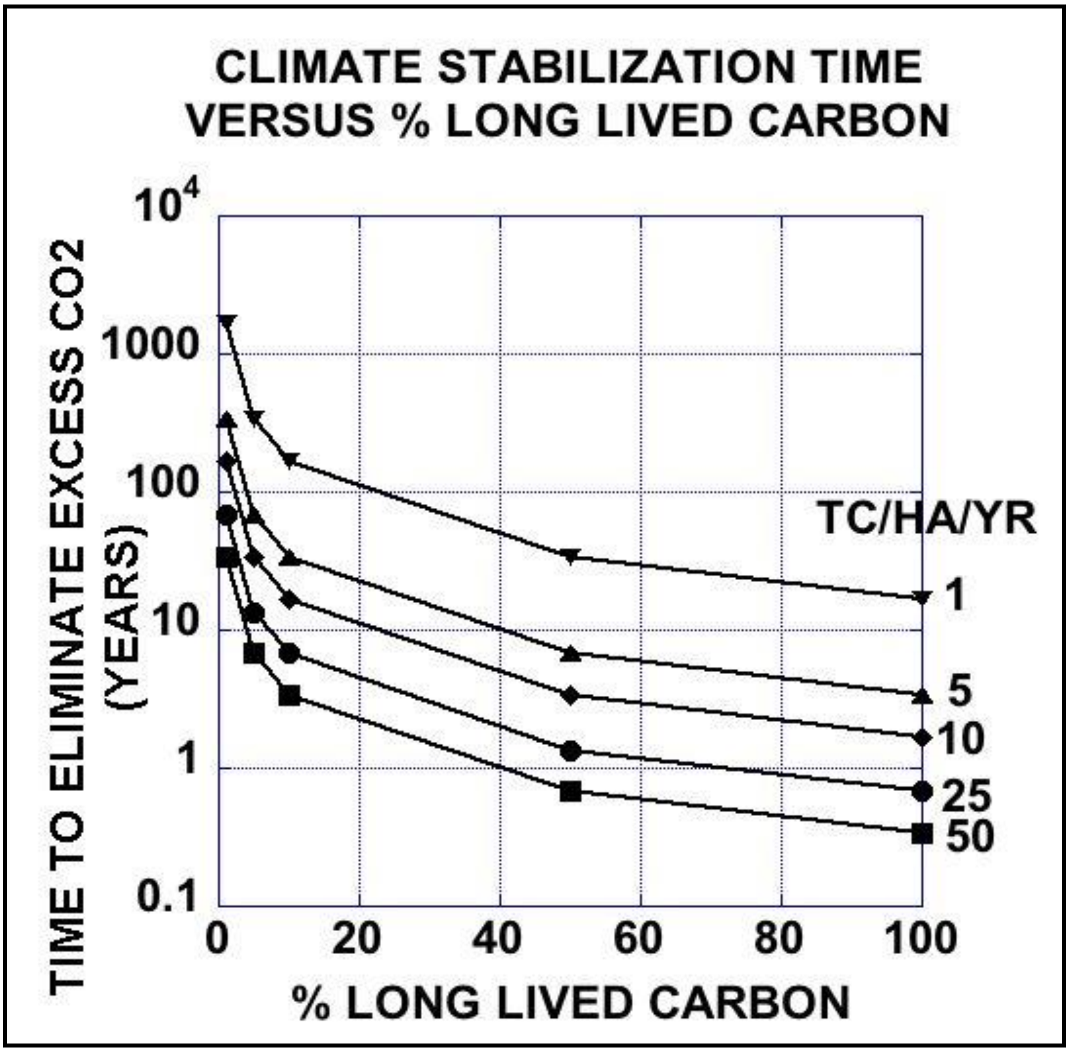
Biochar that has been matured properly greatly stimulates growth of bean seedlings, while raw biochar suppresses their growth. About half of biochar users use mature material, about half use raw biochar. This explains the huge difference in reported results. Goreau, 2020.

There is a genuinely regenerative version of BECCS that uses biomass pyrolysis (heating without oxygen) instead of combustion with oxygen. The heat generated is used for energy, liquid and gaseous vapors used as fuels, and about half of the carbon, as biochar, is buried in the ground (Bates & Draper, 2019). Use of biochar in soil provides carbon negative energy that draws down atmospheric CO_2 and could easily replace what we now use in coal. This sustainable, planet-healing, form of bio-energy is sometimes called Pyrolysis with Carbon Capture and Sequestration, or PyCCS.

Even though regenerative land management that reverses climate change can be done in any ecosystem, and thousands of people are already practicing it to their own economic benefit because it improves their land and their quality of life by producing more with less input), there are still billions of people who don't know better practicing degenerative agriculture, destroying future fertility for immediate profit. If the irresponsible land users used the best practices that the responsible ones do, the global problem food, energy, and climate problems could be quickly solved!

Below we calculate how quickly the carbon cycle can be re-balanced so CO_2 can be reduced to safe, Pre-Industrial levels, as a function of two parameters, the rate at which carbon is added to soils over the surface of the land, and the fraction of that carbon that is long-lived biochar. From these graphs the time to drawdown can be read off for any combination of these parameters. Obviously the more long-lived carbon we can put into soil the faster this will happen. Biochar is extremely variable, depending on the starting biomass and the pyrolysis conditions, and includes the complete range of organic carbon compounds from very short lifetimes (sugar solutions poured on the ground will be consumed by bacteria in hours) to very long (high temperature biochar). Soils need all of them, from junk food for microbes to utterly indigestible. High temperature biochar lasts essentially forever, the first forest fires left behind biochar so perfectly preserved that you can see every plant cell 350 million years later.





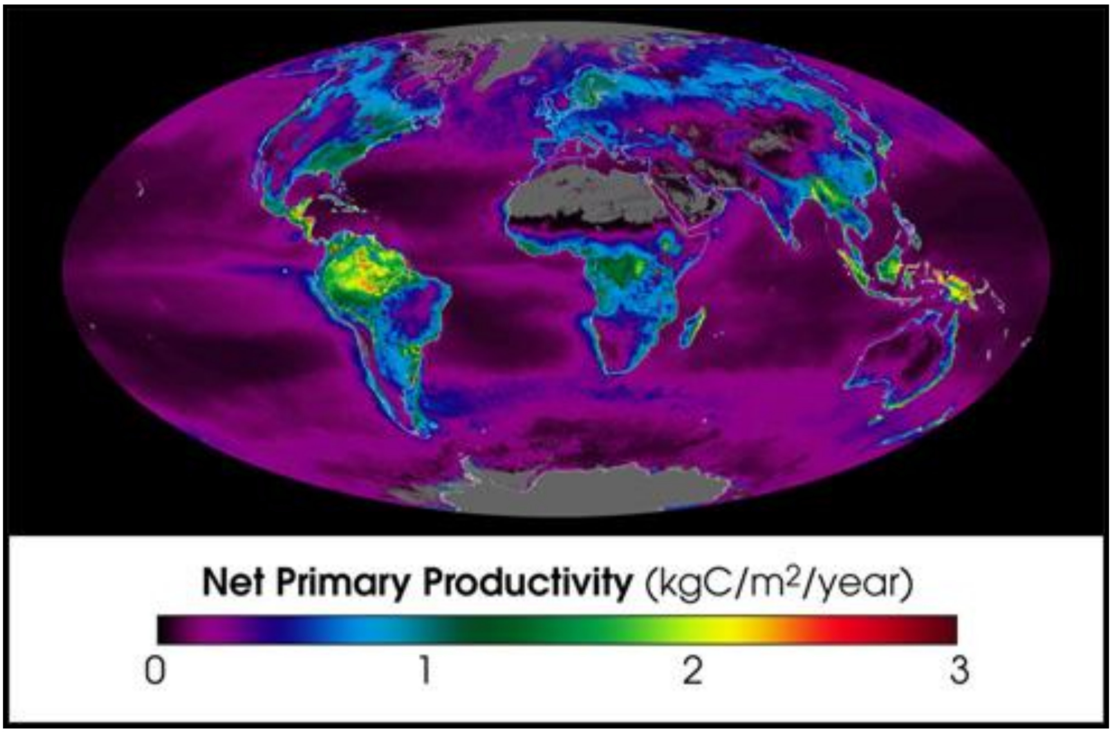
Time to draw down CO_2 to Pre-Industrial levels can be read off these graphs as a function of annual carbon additions to soil and as a percentage of long-lived carbon. Goreau, 2018.

At present, the mix of degenerative farm, pasture, and forest management practices we are using gives soil carbon a negative global lifetime since most farmers are burning up and eroding their soil carbon much faster than they are building it. But if we used best practices world-wide we could reach Pre-Industrial CO_2 levels in decades, and avert the worst consequences of runaway global warming and sea level rise. The task of regenerating our ecosystem and soil carbon storage will be the essential task for remaining generations in this century if our descendants are to survive.

It is important to note that these graphs underestimate the speed that drawdown can be achieved because they show only land soil carbon burial solutions, and not coastal carbon burial solutions, which in fact provide the largest cost-benefits because they can store the most carbon in the smallest area at the least cost. About half of global soil carbon is in wetlands (wetlands, bogs, swamps) and about half of that is in marine soils (mangroves, salt marshes, and sea grasses). Coastal wetlands also bury about half of the organic carbon in the sea in a tiny fraction of its area. Coastal wetland ecosystems occupy less than 1% of the Earth's surface, and they hold more carbon than the atmosphere, yet we have already foolishly destroyed about half of them.

It is very easy to plant mangroves, sea grass, and salt marsh, but most large-scale efforts soon fail because the seedlings are washed away by waves before their roots can grow. The Biorock method, which uses safe low voltage currents, such as from solar panels, greatly increases above and below ground growth of marine plants. Biorock produces such intense root growth that sea grasses quickly attach to bare rock and build up an ecosystem of fishes, mussels, shrimps, crabs, and worms, even though they normally require 5-10 cm of sand or mud for their roots. Salt marsh grass was able to grow in deeper water than it normally could, extending eroding salt marshes seaward. The roots are deeper and proliferate more rapidly, while above ground growth is taller, greener, and has many more stems per unit area. In addition, the Biorock process produces conditions that greatly increase marine soil carbon preservation and sequestration in soil. Applied on a large scale, Biorock would allow coastal ecosystems to again become the world's most cost-effective carbon sinks, while regenerating vanishing coastal fish and shellfish populations, and protecting eroding coasts from global sea level rise, hurricane and storm waves, and tsunamis (Goreau & Trench, 2012).

In contrast to shallow coastal waters, deep ocean waters are very poor sinks for carbon, because the carbon produced in the sea is very efficiently recycled back to CO_2. The only way to turn the deep ocean into a major carbon sink is to pollute it so badly that all the oxygen is used up, turning it into a dead zone, stinking of hydrogen sulfide's rotten egg smell, where dead organic matter piles up without rotting. This means killing the oceans! We are doing so on a large scale along all populated coasts, and to restore the ocean to health we need to recycle all the wasted nutrients and carbon we are bleeding into the oceans from land, which is simultaneously impoverishing the soils and killing coastal ecosystems through massive harmful algae blooms.



Global net primary productivity. The oceans have much lower net productivity than the land, except for near-coastal habitats.
http://science.nasa.gov/earth-science/oceanography/living-ocean/remote-sensing/

Biodiversity: the essential stabilizing force

To flatten the CO2 curve in time to prevent the worst impacts of runaway global warming and sea level rise (such as those that would flood Mumbai, Kolkata, Chennai, and many more major cities in India alone), it will be essential to increase ecosystem carbon biomass storage (especially soils), but also biodiversity, on which the web of ecosystem services that regulate the planet's key ecosystem services, healthy and reliable climate, heat, water, and food.

We can look at planetary ecosystem services in terms of the carbon flows between major components of the global system, in terms of their weight, and in terms of their biodiversity. A diagram of global carbon cycle flows suggests that soil carbon is a major potential sink that could be increased rapidly. The diagram of biodiversity shows each major group of life in order of appearance in Earth's history, sized according to the number of species in each group. If we superimposed arrows between species of width proportional to carbon transfers between them (when one species eats or decomposes another), we would have the entire ecological food web (which would be too complex to read!). This complexity is very important, it stabilizes the entire system because all species are interconnected, even if mostly by indirect pathways. This stabilization does not happen in single species populations, when one individual dies from extreme stress, almost all do, and when one gets a parasitic disease, it passes it on to the rest.

The faster and more efficiently we can maximize carbon re-cycling rates through biological carbon flows into biomass and soil carbon storage, and biodiversity, the faster we can regenerate our critical life support systems and avert the worst impacts of runaway global climate change. This requires a focus on protecting the most biomass-rich and species-rich ecosystems, and regenerating their ecosystem services where they have been destroyed.

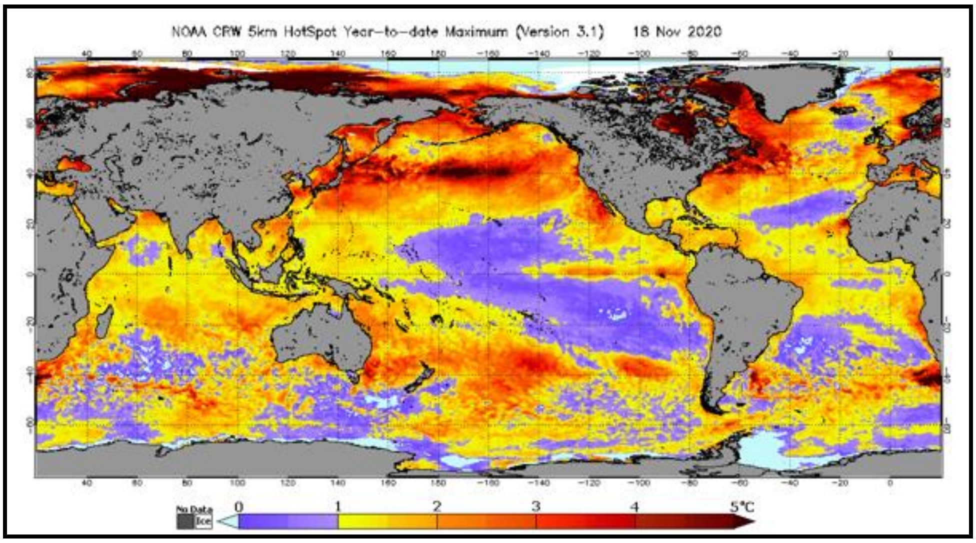
Every visitor to Rio de Janeiro is enchanted by the lush tropical jungle that overlooks the city, and is incorrectly told that it is natural forest in official tourist guide books. In fact, it is entirely planted. When the Portuguese came to Rio de Janeiro, Brazil, in 1500 the mountains were covered with jungle to the very tops. During the coffee boom in the 1700s all the trees were cut down, the soil washed away, leaving bare rocks, the springs dried up, the rivers stopped running in the dry season, and the entire population had to leave to beg for water from other wetter regions. When Charles Darwin visited Rio de Janeiro in 1832 on the voyage of the Beagle, the bald rock mountains were baked brown and bare and had hardly a green bush to be seen on their summits. You can see some of the last bushes that Darwin saw on top of Corcovado, which are now covered by a concrete platform and a huge metal statute.

View of Rio de Janeiro with Sugarloaf Mountain as seen from the Corcovado by HMS Beagle artist Augustus Earle, 1832.

The city was under no illusion why their water supply had vanished, nor about the solution. They hired five slaves who spent decades climbing up the last inaccessible mountain peaks that had been too steep to deforest, and transplanted little tree seedlings, replicating the species diversity of the original forest. Over their careers these environmental heroes planted the vast forest that stands above Rio de Janeiro. When the trees came back, so did the wildlife and the springs, the rivers flowed year-round again and supplied the city water.

Amazingly, for a human-planted forest, it has entirely regained its carbon and nitrogen ecosystem storage and recycling services. When we measured greenhouse gas emissions from the soils about 150 years later, they had recovered to the level of pristine Amazon rainforests (Goreau & de Mello, 1985, 1988; de Mello & Goreau, 1998). Sadly, in Brazil the lesson was not learned, most reforestation has been with exotic Eucalyptus mono-species plantations. There are no birds, animals, or insects in these mono-species forests, and dead leaf litter piles up without decomposing until it is a fire hazard. I have seen the same in Borneo, where some of the richest rainforests in the world were turned into plywood, and then replaced with mono-species plantations of wood for harvest, causing horrific loss of soil and nutrients, bleeding them into rivers that are choking the life out of some of the world's richest coral reefs offshore.

In the ocean almost all efforts at ecosystem restoration, from mangroves, salt marshes, sea grass, oyster reefs, and coral reefs, grow single species. When the water gets too hot, muddy, or polluted, they die together. In contrast, the Biorock method greatly accelerates the settlement, growth, survival, resistance to extreme environmental stress, and reproduction of all ocean species we have looked at. Biorock reefs are constantly gaining biodiversity as new species settle on them and migrate, becoming even richer in corals and fish than they had been before they had been, even in Indonesia, the global center of marine species diversity. In Jamaica a one-year old Biorock reef about one square meter in area had more than 100 species of coral reef life on it (Goreau, 2012). Biorock Indonesia is growing most of the world's coral species on Biorock Coral Arks, which survive the severe bleaching that is wiping out coral reefs across the world. Earth passed the temperature tipping point for mass coral bleaching in the 1980s, and Biorock is the only method known that allows corals to survive lethal conditions, because it uniquely acts to directly stimulate the biochemical energy production and health of all marine species (Goreau, 2014).



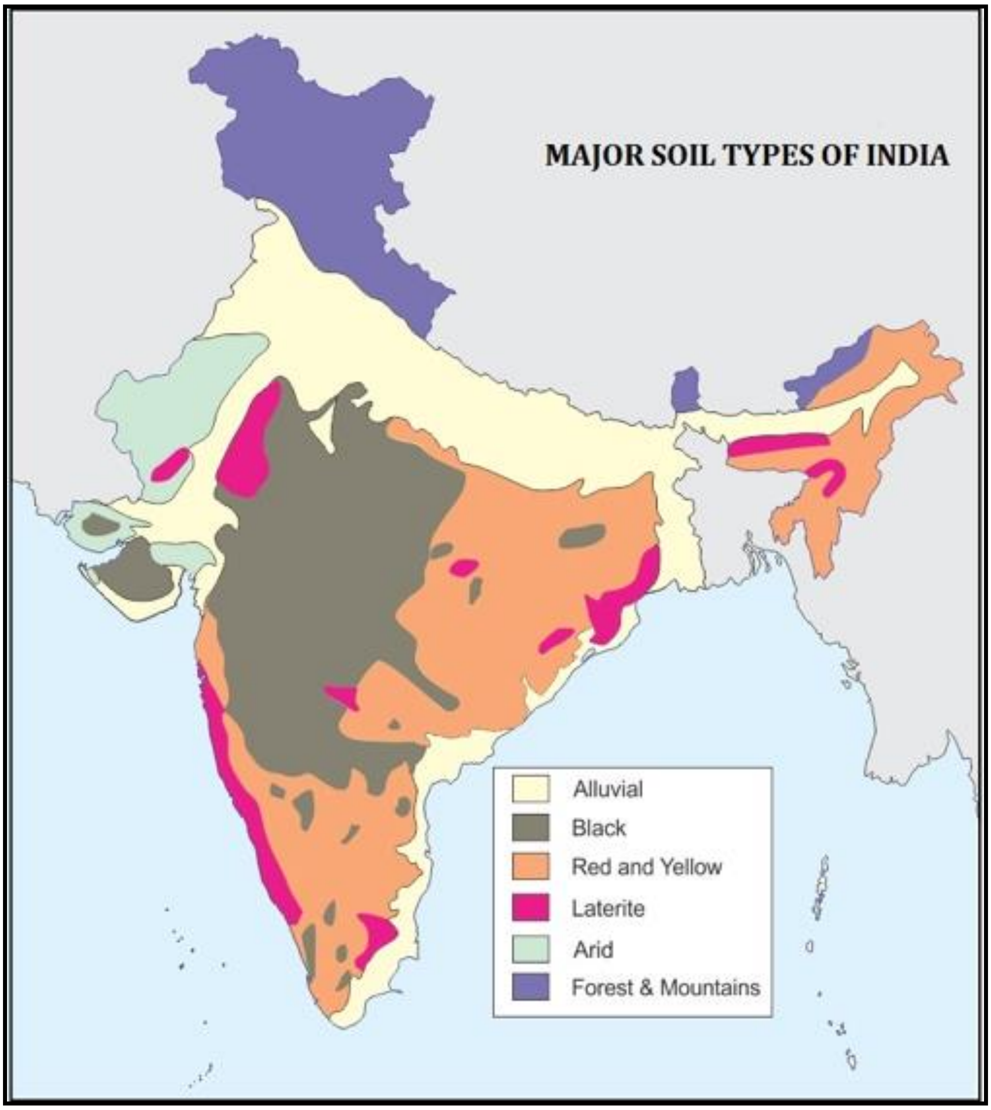
Maximum coral bleaching HotSpot for 2020. Coral reefs in all yellow, orange, and red areas would have bleached.
https://coralreefwatch.noaa.gov/product/5km/

Regenerating India's terrestrial ecosystem services

The people of every country in the world would benefit from regenerative development strategies, both individually and collectively, and even more so, will their descendants. Here we look at some aspects of how these could be applied in India, soon to become the largest country in the world by population. Population pressure is manifested by the near total disappearance of the vast jungles that covered the subcontinent in Pre-Vedic times. There is little if any undisturbed habitat, even the most remote forests have been intensely harvested for thousands of years by Indigenous Forest Tribes (Bawa et al., 2007).

Increasing Indian agriculture production has generally been regarded as a problem of water supply, suitable crop varieties, and chemical fertilizers, needed due to low fertility soils in most of India. India's soils have borne the burden of heavy losses of nutrients from intense cropping, burning, soil erosion, and leaching, and almost all soils are deficient in one or more of the 20 or so elements essential for life, only three of which are included in conventional commercial fertilizers. Since cattle dung is used as fuel, fertilizers used are usually chemical mixtures of soluble nitrogen, phosphorus, and potassium compounds (NPK). These are intrinsically unbalanced because plants need around 20 different elements for balanced growth, and insufficient amounts of any of the other 17 trace elements (other than N, P, & K) prevents plants from taking up NPK, with the result that most of the fertilizer cannot be utilized by plants, and instead is flushed out of the soil in the rainy season, contaminating groundwater and surface waters, and causing coastal eutrophication, massive growth of harmful algae that overwhelm fisheries habitats like coral reefs, replacing them with spreading dead zones.

India has a large variety of soils due its complex geological history and climate. The alluvial soils in the north, derived from river-borne erosion of geologically recently uplifted rocks in the Himalayas, and the black soils of the Deccan Plateau, are the darkest, highest in organic matter, and most fertile, while the lighter colored soils which cover most of India, whether red, yellow, or khaki are generally devoid of many or most essential elements, lowest in organic matter, the least fertile, and the most prone to erosion.



Simplified map of major soil types of India.
https://www.topperlearning.com/answer/1mark-the-major-soil-types-in-india-in-a-political-mapa-and-write-any-three-characteristics-of-each-soil-type-2define-the-following-terms-counter-plou/n3yjnqll

A map of India's major soil types reveals tremendous opportunities for India to re-mineralize soil fertility and become much more productive. In the extreme north are the rocks of the Himalayas, subject to tremendous erosion and weathering of fresh minerals that are dumped by rivers from the mountains into the Gangetic Plain. These soils are intrinsically fertile because of their fresh minerals, but heavily leached by rain and irrigation, and the contaminated groundwater is being depleted at the fastest rate on Earth, measurable by the gravitational pull on space satellites.

All Indian soils would greatly benefit from organic matter, especially biochar, which holds water and nutrients (Lal, 2004; 2020), reducing losses and contamination, while extending the growing season. Biochar can be made from any carbon containing material, but its production should not compete with food production. Instead it should be made from the invasive weeds that are making large parts of India unusable, especially the noxious plague of the invasive introduced North American tree *Prosopis juliflora*, whose thorns make its leaves inedible even to goats, and a hazard to chop for firewood. Huge areas across India have turned to useless *Prosopis* thorn bush. Converting its biomass to biochar would trap the nutrients (*Prosopis* is high in nitrogen) in vegetation and soil and make them available to tree crops bearing food, fruits, fibers, and raw material feedstocks for bioplastics, shading and cooling the newly productive land while building up biomass and soil carbon. India's Forest People have ancient experience in selecting and propagating such plants (Bawa et al., 2007).

Land over-run by invasive *Prosopis juliflora* should have the trunk biomass converted to biochar (and energy), the biochar matured with Deccan Basalt powder and composted *Prosopis juliflora* leaves, as natural long-lasting, slow-release fertilizer for tree planting on land that is now useless to be converted to food forests. This would greatly improve the biomass, biodiversity, and useful biological production of all soils in India, and create important new carbon sinks to reduce climate change. Pilot projects should be started by the Forestry Department of India this year to prepare for large scale implementation across India throughout the UN Decade on Ecosystem Restoration, 2021-2030 (https://www.decadeonrestoration.org).

Large areas of India are composed of light-colored soils, red soils, and yellow soils that are extremely deficient in minerals, and would benefit immensely from basalt rock powder and biochar. India has vast supplies of basalt, the black soils lie over the Deccan Plateau, the largest basalt formation on earth. India could easily improve soil fertility across the entire country using domestic materials.

Food forests are an ancient practice of the India's indigenous tribal forest people, whose knowledge of the plants and experience of their needs and uses are essential and recognized by Biodiversity conservation efforts in the Western Ghats and Eastern Himalayas by the Ashoka Tree Foundation, led by Professor Kamaljit Bawa and colleagues. To become much more productive they need to supercharge their soil fertility with long-lasting slow-release natural fertilizers.

Use of natural, long-lasting, slow-release fertilizers could balance soil elemental ratios to create much more fertile soil capable of bearing much more productive crops, agroforestry, or pasture. The ratios needed depend on the availability of suitable natural fertilizer materials, the needs of the plant (which varies from crop to crop), and the specific nutrient limitations caused by the chemistry of the soil (which varies depending on climate, geology, topography, and land use by humans).

The least fertile soils will benefit the most from basalt rock powder, which provides all the other elements that plants need which they do not take up from air and water (carbon, oxygen, hydrogen and nitrogen). The Deccan Plateau is the world's largest basalt body, so India is exceptionally rich in this natural fertiizer. All soils will benefit from biochar because of its water and nutrient holding capacity. Biochar can be made from any carbon containing material, but best of all from the invasive plants that are now over-running ecosystems and suppressing biodiversity.

Prosopis juliflora, the noxious invasive tree overwhelming India, should be used to produce biochar, turning areas now covered with impenetrable thorn bush back into highly diverse fruit tree forests. A pilot project would require a biochar kiln, which could be built to provide additional heating, crop drying, gaseous and liquid fuels, liquid fertilizer, and biochar for soil. Trunk and stem biomass would be used for biochar, and leaf biomass composted. The biochar is then mixed with basalt powder and compost (the source of nitrogen) and matured for a year before use. This combination is essential, mature biochar is a powerful plant growth enhancer, but immature biochar inhibits plant growth! It is recommended that the Forestry Department of India start pilot projects in different soil types and climates, with a scientific advisory panel of India's leading soil scientists and ecologists.

Regenerating India's coastal ecosystem services

India's coastal fisheries, one of the world's largest, is in severe decline due to overharvesting, pollution, and ecosystem collapse. Coastal coral reefs, mangroves, salt marshes, and sea grass habitats could readily be regenerated with solar or wave powered Biorock electric reef technology, regenerating coastal fisheries and shore protection from rising sea level, cyclone waves, and tsunamis, while storing vast amounts of carbon.

India, like all coastal countries, is hemorrhaging carbon, nitrogen, and phosphorous into the sea, impoverishing its soil fertility, requiring replacement with expensive and wastefully used chemical fertilizers. These nutrients are killing the biodiversity of its most productive marine ecosystems with harmful algae blooms, severely damaging coastal fisheries and natural shore protection by coral reefs and mangroves from cyclone and tsunami surges as well as rising sea level. For a recent example: Experts worried about Algal bloom in Coastal Karnataka
https://m.timesofindia.com/city/mangaluru/experts-worried-about-algal-bloom-in-coastal-karnataka/amp_articleshow/78234508.cms

Biochar and rock powder traps nutrients to be recycled on land, keeping them from killing marine ecosystems. Biochar and rock powder can be used to treat sewage and agricultural runoff so the nutrients can be reclaimed and recycled on land. There are enormous possibilities to clean up the severely polluted rivers, canals, tanks, ponds and wetlands in India, for example the Calcutta wetlands and the Backwaters of Kerala. Once the harmful algae disappear due to lowered nutrients, these waters can be used for highly productive and diverse Biorock mariculture of fish, shellfish, and algae (Goreau, 2018).

To prevent these negative pollution impacts, India should recycle waste nutrients into more productive uses on both land and sea, increasing fisheries and CO_2 sinks. The solution lies in trapping these valuable lost elements and recycling them as close to the source as possible, greatly increasing useful biomass, carbon storage, and fish and shellfish productivity, instead of harmful weeds.

The UN Decade on Ecosystem Restoration and the UN Decade of Ocean Science for Sustainable Development will require all ecosystems to increase carbon storage if it is to flatten the global CO2 curve and prevent runaway global warming. India's coastal wetlands, mangroves, salt marshes, and sea grasses, are the most cost-effective places to store carbon. If these ecosystems are regenerated, they will regenerate coastal protection from cyclone and tsunami surges and from global sea level rise, and coastal fisheries (since these ecosystems are the major juvenile nursery habitats for marine fishes and shellfish).

Most Indian rivers, lakes, and groundwaters are severely polluted with nutrients derived from human wastes and fertilizers, most, have become sewers, with catastrophic effects on India's fresh water and coastal biodiversity (like the Ganges dolphin) and fisheries (https://thefishsite.com/articles/scarce-freshwater-fish-pose-danger-in-india). In the coastal zone these wastes provide intense local sources of high nitrogen and phosphorus that cause massive harmful algae blooms of two types:

A) Cyanobacteria (often called "Red Tides"), many of which release toxic chemicals that can poison fish, other marine life, and humans, causing sudden die-off syndromes noted when dead fish and marine life piles up on the shore, and people get sick from eating poisoned fish and shellfish. Another phytoplankton problem is dinoflagellates taking over, because the zooplankton that fish feed on don't like to eat them, so they die and pile up rotting on the bottom, consuming oxygen from the water and causing spreading dead zones barren of life except for microorganisms.

B) Weedy fleshy "macrophyte" algae, which smother and kill coral reefs and sea grass beds, destroying their function as high quality juvenile fish and shellfish habitat for shelter and food, wiping out productive biomass from the bottom up due to habitat degradation and destruction, while fisheries are being simultaneously overharvested from the top down.

Two innovative strategies are recommended to regenerate India's collapsing marine ecosystem services by redirecting wasted nutrients into increased useful production:

1) stimulation of diatom growth to feed zooplankton and fish in fresh water, estuaries, and marine environments,

2) stimulation of coral reefs, mangroves, sea grass, and salt marsh growth with safe weak electricity from solar panels and wave or current generators to protect coasts from erosion, to provide essential nursery ground for fisheries, and to store carbon from the atmosphere to reverse global warming. At the same time Biorock has tremendous potential for complex whole ecosystem sustainable mariculture (Goreau, 2018).

1) The first uses concentrated micro-nutrient solutions to provide the critical elements that diatoms need to outcompete cyanobacteria and dinoflagellates, redirecting wasted carbon and nutrients towards food chains that feed highly desired food fish, such as hilsa (*Tenualosa ilisha*), India's most popular food fish, whose populations have catastrophically declined in both size and numbers due to overfishing and pollution of rivers, estuaries, and coastal waters. The diatom stimulants, called Nualgi (http://nualgi.com/product.html), have been developed by Sampath Kumar Thothathri and M. V. Bhaskar.

Bhaskar points out that (2020, personal communication, https://www.nualgilakes.com/whats-nualgi, https://nualgiponds.com/):

"Nualgi is a liquid in small bottles, when it is poured into any natural water the native Diatoms present in the water consume it and grow rapidly. All eutrophic waterways have Diatoms. Nualgi does NOT contain any Diatoms. It contains 10 micro-nutrients adsorbed on Nano Silica, since Diatoms require silica they consume Nualgi and other phytoplankton do not, thus Nualgi is an unique solution to deliver micronutrients to Diatoms in large natural waterways, in which many types of phytoplankton are present. We can thus prevent or end Cyanobacteria or Dinoflagellate bloom and ensure that Diatoms dominate. Since Diatoms are consumed by Zooplankton, oysters, fish, etc., the Carbon, N and P go up the food chain and Oxygen remains in the water. Cyanobacteria and many species of dinoflagellates are not consumed by zooplankton and small fish, since they cannot digest the cellulose cell wall, so most of the Cyanobacteria bloom dies and the bacteria that decompose them consume oxygen from the water, causing fish kills, dead zones, etc."

NuAlgi (http://nualgi.com/product.html), provides trace elements that allow diatoms to grow instead of harmful algae, and diatoms provide food for very productive oysters and fishes, like India's favorite food fish, the Hilsa. The Nualgi method should be tried in eutrophic areas of declining fish catch such as the Sundarbans, the East Kolkata wetlands, the Back Waters of Kerala, and the delta of the Kaveri river, where a whole-watershed monitoring plan might allow estimates of the efficiency of nutrient trapping and recycling into new production.

2) Mangrove (Mitra, 2019), seagrass (Geevarghese et al., 2017), and salt marsh (Banerjee et al., 2017) ecosystems are India's most important fish nurseries and probably India's largest carbon sinks, but they are subject to dredging and severe pollution from garbage and sewage. All are easy to plant, but most planting efforts fail because waves wash seedings away before they can grow roots. Mangrove planting saved entire Tamil Nadu villages from the Asian tsunami, as well as providing their food, while adjacent villages where mangroves had been cut were devastated (Kathiresan and Rajendran, 2005).

The Biorock trickle charge method has used solar panels to greatly accelerate the above and below ground growth, survival, biodiversity of seagrass and saltmarsh, allowing them to be grown where they could not otherwise grow. The method works with all forms of marine life, including corals, oysters, mussels, sea grass, saltmarsh, and mangroves. The method is now being uses to regenerate coral reefs in Kachchh, Gujarat (http://www.globalcoral.org/first-biorock-projects-in-india/#:~:text=The%20first%20Biorock%20coral%20reef,India's%20top%20coral%20expert%2C%20Dr) and should be expanded to coral habitat around India. It is recommended to test the Biorock regeneration method for mangrove, seagrass, and saltmarsh regeneration in India at suitably monitored sites, such as the Sundarbans, the Kerala Backwaters, Gujarat, and the Gulf of Mannar.

There are many opportunities to convert harmful degenerative food chains into useful regenerative ones. The huge amounts of sewage and fertilizer nitrogen and phosphorus flushed into India's fresh and coastal waters causes massive blooms of cyanobacteria, many of which are toxic, and rot on the bottom, stripping oxygen out of the water and killing fish.

If these two methods are shown to work well in India, large-scale implementation could help trap waste nutrients that are now killing productive marine ecosystems, and re-channel them into useful fish and shell fish production, while increasing coastal fish and shell fish populations, shore protection, biodiversity, and carbon sequestration.

India and every country can act immediately to reverse climate change and improve their own quality of life now and for the future. The sooner this is done, the faster the results at the lowest cost. The task of growing our way to the upper right corner of the habitability cube, instead of falling to the bottom and needing to be metaphorically intubated on a ventilator, could be accomplished in a generation or two if we followed sound science-based policies worldwide.

Healthy coral growing on Biorock electric reef, Kachchh, Gujarat. Photograph by Dr. Chandran Retnaraj.

Biorock reefs form excellent habitat for fish and shellfish as well as corals. These fishes moved immediately into a Biorock reef in Kachchh, Gujarat. Photograph by Dr. Chandran Retnaraj.

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