Compendium of Scientific and Practical Findings Supporting Eco-Restoration to Address Global Warming

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Preface

This Compendium of Scientific and Practical Findings Supporting Eco-Restoration to Address Global Warming (the "Compendium") is a fully referenced compilation of the evidence outlining the power, benefits and necessity of eco-restoration to address global warming. Bringing together findings from the scientific literature, government and industry reports, and journalistic investigations, it is a public, open-access document that is housed on the website of Biodiversity for a Livable Climate (bio4climate.org).

This is the pre-release of the First Edition, a DRAFT document for distribution at our ninth conference, Scenario 300: Making Climate Cool!, in Washington, DC on April 30, 2017. This pre-release is a sample of what we anticipate from the first major release, tentatively scheduled for June 15, 2017. As a draft there are still inconsistencies in formatting and style, and we ask our readers to bear with us as we refine our editorial process. We invite comments and suggestions from you, the reader, to help make this document as useful as possible.

The Compendium is intended as a living document, and there will be regular additions between releases as the relevant literature evolves. In the past few years there has been a dramatic growth of information that supports the power of the natural world to address the causes and effects of climate change. The climate conversation has expanded dramatically beyond greenhouse gases, and is repositioning global loss of biodiversity and destruction of ecosystems as root causes of global warming and many associated environmental problems.

There is no central field of study that aggregates the information relevant to eco-restoration and climate; there are, however, many fields that contribute. The result is a solid body of evidence that argues compellingly for a focused effort on the part of governments, civic organizations, NGOs and, especially, local communities and individuals to take the lead on regenerating degraded and desertified land and waters worldwide.

The evidence is abundant, and our goal is to gather it in one place to make it readily available for public scrutiny. We will present information from papers from the peer-reviewed literature, non-profit organizations, government bodies, commercial publications, and the popular press. All have valuable contributions to make from different perspectives that together paint a picture of a new, healthy and attainable world, a sample of the people who are helping us to get there, how to get there using nature's low-tech tools, and the arguments that propel this pressing journey forward.

It behooves us to acknowledge that an exclusive focus on greenhouse gas emissions is a major obstacle. This is not a statement made lightly, as longstanding bodies of knowledge should not be dismissed whimsically. And yet, as paradigms fail to reconcile reality with assumption, they should be retired in the service of scientific progress.

This is the situation we are in today with two competing although not entirely mutually exclusive worldviews:

> Old paradigm: Climate change is a consequence of elevated greenhouse gases
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> vs.
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> New paradigm: Climate change is a consequence of global ecological destruction.

It's important to note that the old paradigm has provided many important insights critical to the new paradigm, and we should learn from the investigations into the old paradigm even as the paradigm as a whole comes into question. We need to work together towards a common goal, a healthy and abundant planet, while keeping in mind that each paradigm leads to a very different set of outlooks, studies, behaviors and outcomes.

Evidence for paradigm shifts builds slowly, acceptance even more so. Indeed, one of the problems we face with this Compendium is that we're not just considering changing land management practices, we're of necessity examining and questioning some of the core assumptions of current mainstream science. We are facing a culture shift of difficult and dramatic proportions.

We are aware that there are many studies that present significantly lower estimates of the potential for building soil carbon, managing water cycles, and eco-restoration in general. It is our position that for the most part, while those studies may present useful data, their perspective is limited by mechanistic assumptions and reductionist, non-systemic methodologies. Therefore we mostly do not include these studies in this Compendium (some, however, are illustrative and helpful). This is admittedly a bias on our part, an intentional one aimed at offsetting the virtually ubiquitous bias of the mainstream paradigm. The reader may readily find the mainstream literature for extensive review, and we welcome critical examination of both the mainstream literature and of the literature presented here in an effort to promote the best possible outcomes for biodiverse life on earth.

In sum, the clear intent of this Compendium is to fortify the case for eco-restoration as a primary and essential solution to global warming, one that could potentially yield benefits more quickly and safely than any other solution currently being proposed, and to move it forward with all due haste.

Finally, we’re not attempting a definitive “proof,” an elusive pursuit in a scientific arena in any case. Rather, we’re presenting evidence of real and practical possibilities, along with solid research in fields, some of which are newly discovering (with occasional surprise) that they’re related in mutually productive ways in a kind of scientific symbiosis.

It is truly time to move science and practice beyond present assumptions. We provide examples from a variety of regenerative approaches that illustrate how we may expand the current boundaries of mainstream evidence and legitimate paradigms - and perhaps even use our innovative and growing practical and scientific understandings to reverse global warming.[1]

About Biodiversity for a Livable Climate

Biodiversity for a Livable Climate, bio4climate.org is a non-profit founded in 2013 whose mission is to support the restoration of ecosystems to reverse global warming. We are a think tank and educational organization, presenting conferences on the science and practice of ecorestoration with speakers from across the world, along with outreach to other organizations and groups to share this message and vision. Climate affects everyone, every organization has to deal with it in its own way, and we are learning how to help.

Suggested Citation

Compendium of Scientific and Practical Findings Supporting Eco-Restoration to Address Global Warming, https://bio4climate.org/resources/compendium/. This is a collection of references that will grow as new literature becomes available, and as older literature is re-discovered.

Acknowledgements

Current reviewers and contributors to this collection are Hannah Lewis, Adam Sacks, Robert Blakemore, Andrew Blair and Gina Angiola The contributions from our many speakers and collaborators cannot be overstated. We invite our readers to review our collection of conference videos on the program page of each of our nine conferences to date.

We are most appreciative of the support from our sponsors over the past three years. In particular, the 11th Hour Project provided significant funding for our first two years, and the new and important institution that it helped create, the Regenerative Agriculture Foundation, is

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[1] For a more thorough discussion of needed paradigm shifts, see From Paradigms to Peer Review in Appendix A.

continuing its strong moral and financial support. We are also pleased to acknowledge generous conference sponsorship from the Organic Consumers Association, Regeneration International, the Virgin Earth Challenge, Bristol Community College, and the Tufts Institute of the Environment. Additional important support has been kindly provided by the Nutiva Foundation, the Savory Institute and the Bionutrient Food Association.

We also gratefully acknowledge support from several institutions, including Tufts University, Harvard University, Bristol Community College and the University of the District of Columbia.

The format of this Compendium is borrowed from the excellent example of the [Compendium of Scientific Medical and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction)]() by the Concerned Health Professionals of New York and Physicians for Social Responsibility.

Abstract

There is substantial evidence that we can address the climate crisis by intensive global eco-restoration: drawing down vast amounts of carbon from the atmosphere into global soils through photosynthesis; managing water cycles to cool the biosphere; restoring biodiversity and degraded terrestrial and aquatic ecosystems.

Support for an eco-restoration hypothesis is solid and comes from a wide variety sources, both in academic science and modern and traditional land management practice. Eco-restoration may be applied in numerous ecosystems: croplands/agroecosystems; estuaries; forests; marine ecosystems; shorelines; pastures and rangelands; oceans; wetlands; and others.

One of the challenges at this point in time is to collect available evidence from sources spread across many disciplines, in different formats, synthesize it, and present a comprehensive, logical and compelling case that efforts must be focused on regeneration of large areas of the planet in order to address global warming successfully and rapidly.

In this paper we attempt to connect these disparate sources and create a constructive narrative to move from the current climate paradigm, where global warming is narrowly defined as a problem of excessive greenhouse gases, to a new climate paradigm, where global warming is defined as a systemic problem resulting from global anthropogenic destruction of the natural world.

We begin with an essential discussion of how paradigms both promote and constrain research and discovery. A key point is that a shift in paradigms opens many positive possibilities for addressing climate through eco-restoration, possibilities that are outside the scope of the current paradigm. The latter is limited to reducing fossil fuels emissions and has little if any success to date based on annual increases in atmospheric greenhouse gas burdens and rising global temperatures. Notwithstanding technological advances, it furthermore has uncertain future prospects, especially considering the accelerating warming we are seeing today.

We further explore an idea that has been overwhelmed by our current preoccupation with powerful technologies, i.e., that living systems are the most powerful force affecting planet earth throughout the biosphere. Thus, it is in living systems, not technology, where the solutions to global warming reside.

We also address historically healthy natural systems that were bountiful in ways that are mostly lost to modern human experience. Collectively, humans have gradually whittled away at the power of the natural world through environmental overshoot and destruction over hundreds of generations, until widespread environmental collapse - including mass extinction, desertification and global warming - appears inevitable. When we begin to grasp the potential productivity and broad benefits of healthy ecosystems, we discover a hopeful new roadmap for addressing present dilemmas.

Finally, in Appendix A we discuss the conceptual and psychological obstacles to a paradigm shift, as postulated by Thomas Kuhn in his highly influential 1962 book, *The Structure of Scientific Revolutions* [Kuhn 1962]. It is our hope that Kuhn's insights will assist in understanding the current scientific roadblocks, and in proceeding with the necessary transition.

We conclude that it is possible, even this deep into climate, extinction and eco-destruction crises, for successful environmental outcomes for a biodiverse spectrum of species, including *Homo sapiens*. The challenge is largely overcoming resistance inherent in the human dominant culture, including scientific, technological, social, political and economic beliefs. Such resistance is the primary obstacle. Otherwise we can solve these problems with readily available resources and little or no technology, provide for satisfying and productive lives in local habitats everywhere, make ample food and water available to existing populations (all the while supporting just and humane approaches to population reduction), prevent droughts, floods and conflicts over resources, and all for relatively little expense.

While this may all sound too good to be true, these are not separate problems. By solving the one key problem, a natural world in utter anthropogenic disarray, it is possible for all the pieces to fall into place.

Introduction

In order to re-evaluate our approach to climate change in the anthropocene and to find solutions beyond reduction of carbon emissions, we will need to consider the situation from a systems perspective. That is, to acknowledge that we're not simply dealing with recent energy imbalances disrupting millions of years of relative stability in planetary temperatures. And to acknowledge that the prevailing belief that these changes are driven primarily by geophysical phenomena unrelated to biological systems may be erroneous. To the contrary, we emphasize the point that anthropogenic global warming is an extremely complex phenomenon, one driven primarily by human impacts on the biological processes of all kingdoms of life.

There is no question that planet earth is seriously warming at accelerating rates; however, It is increasingly apparent that the greenhouse gas premise of climate science is seriously flawed, and possibly fundamentally incorrect. That global warming is simply a consequence of atmospheric concentrations of greenhouse gases, especially carbon dioxide, is a persistent hypothesis that has its origins in the modern physical sciences beginning around two hundred years ago. This greenhouse gas hypothesis must now be subject to closer examination.

While it is well established that greenhouse gases do trap heat in the earth's atmosphere and that the resultant energy imbalance (trapped heat) from the burning of fossil fuels has increased greenhouse gas concentrations and planetary warming, global warming is largely treated as a geophysical phenomenon isolated from planet earth as a living, dynamic system. Isolating variables is a primary tool in mainstream science, and often leads to overlooking systems behavior that bears no resemblance to the behavior of any of its parts.

Living things are generally regarded as victims, not drivers, of climate change. This view is starting to change, but slowly, whereas global warming is a pressing emergency not allowing for the normal course of a paradigm shift, over at least one generation if not more, to take place.

We must therefore develop a new paradigm, that of global warming as a phenomenon of biology and ecosystem function. While greenhouse gases are a factor and can make climate matters worse, the current controlling factors are management of land, soils, and carbon and water cycles. Extremely high levels of greenhouse gases may indeed overwhelm the entire planetary system eventually, but based on ongoing success of eco-restoration projects around the world we do not yet appear to be at that point. Until such a time, which we strive to see never arrives, we have many positive options.

The challenge in promoting eco-restoration as the primary approach to addressing global warming is that the scientific literature supporting such efforts is diffuse, spread across many disciplines, sometimes with few obvious connections. There currently exists no dedicated journal that intentionally collects studies from fields as disparate as rangeland science, paleontology, soil science, microbiology, agronomy, evolutionary biology, mycology, entomology, oceanography, limnology, and many many others - not to mention human psychology - and relates findings directly to climate, its effects, mechanisms, and solutions.

This Compendium will look at some of the elements of planetary climate and systems function, and attempt to weave them together to create a comprehensive systems view, which will offer opportunities for many different and powerful nature-based approaches for dealing with changes in planetary function, particularly climate.

There are a number of assumptions that we need to reconsider if we are to see our way clear to a new, more effective climate paradigm. Once we have drawn a picture of the new paradigm and the previously unrecognized connections among studies that the paradigm enables, the research and data will acquire new meaning, sense and purpose.

Life as a Geological Force[2]

Going back almost 4 billion years, a scant half-billion years since the formation of planet earth from cosmic dust, life began to appear. It persisted through eons of celestial, tectonic and climatic upheaval. Around a billion years later life, in the form of microbes, found the driver's seat and has taken over the world ever since. In an anthropocentric culture that creates gods in its own image, we are not generally aware that millions of species of living things have molded this planet, turned it blue and green, and created most of its features, from an oxygen atmosphere to geological formations to proliferation of millions of other kinds of living things. Without life, Earth would be merely another rock whizzing through space, like Mars or Venus.

The power of life is especially important in discussions of and action on climate change, since mainstream climate science views living things as victims of global warming, not primary drivers of potential climate solutions. This is most unfortunate since our current obsession with greenhouse gas emissions as a root cause of climate disruption has led us to a dead end. For even if we were to go to zero emissions immediately, due to positive feedback loops and a seriously degraded biosphere, climate chaos would likely continue to accelerate and rage out of

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[2] See Westbroek 1991. His research is based on the groundbreaking work of Russian systems scientist and biogeophysicist, Vladimir Vernadsky (1863-1945). Vernadsky's work is relatively unknown in mainstream science, which is still fractured into narrow disciplines where systems thinking is more theoretical than operational reality. See Vernadsky's signal work, *The Biosphere*, in an excellent edition annotated by Mark McMennamin with a forward by Lynn Margulis, Copernicus/Springer-Verlag, 1998

control.[3,4] It is therefore not unreasonable to pursue the possibility that living things are able to remove the requisite carbon from the atmosphere and cool the biosphere, and in fact there is ample evidence that such is the case.

COMPILATION OF STUDIES AND FINDINGS

Water

With the rise of civilizations, humans began having significant impacts on bodies of water and the water cycle. The early "hydraulic civilizations" appeared along major rivers (Nile, Tigris-Euphrates, Indus, Yellow River and others), changed watercourses and built canals for agriculture and transportation purposes. As populations and cities expanded, demand for food led to soil depletion while the built environment created growing areas of impermeable surfaces. Disruption of water cycles has reached a peak since the industrial revolution, with large areas of land covered with impermeable surfaces, and rainwater and waste rapidly shuttled away from land into the oceans. [Kravčik 2007: 42 ff.]

Water management requires yet another paradigm shift, parallel to the paradigm shift in climate from greenhouse gases to eco-restoration, and fortunately there are many successful water restoration projects under way, along with a strong theoretical basis to guide them.

Kravcik 2007. Michal Kravčík and co-authors are Slovakian hydrologists who have developed what they call a new water paradigm for managing water cycles, floods and drought.

In a healthy water cycle, while some rain enters streams and rivers directly and is carried off to sea, most rain water is absorbed by the soils *in situ*, where it lands. The rain gives life to the soil and sets many biological processes in motion, where it is essential for stable soil carbon storage and cooling the biosphere. This includes evapotranspiration from plants which returns water as vapor to the atmosphere where the water condenses and falls as rain. The cycle then begins

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[3] "A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, *except in the case of a large net removal of CO_2 from the atmosphere over a sustained period* [emphasis added]" [United Nations 2013: 26].

[4] "The growth rate of climate forcing due to human-caused greenhouse gases increased over 20% in the past decade mainly due to resurging growth of atmospheric CH_4 [methane], thus making it increasingly difficult to achieve targets such as limiting global warming to 1.5°C or reducing atmospheric CO2 below 350 ppm. *Such targets now require "negative emissions", i.e., extraction of CO2 from the atmosphere* [emphasis added]," [Hansen 2016: 1]

anew. Kravčík et al. call this the “small water cycle,” where most water goes through its cycles locally. The “large water cycle” is the exchange of water between oceans and land, and “above land water circulates at the same time in many small water cycles which are subsidized with water from the large water cycle.” [Kravcik 2007: 16]

Civilizations disturb healthy water cycles and accelerate the runoff from land by creating impermeable surfaces (including degraded farmlands and rangelands), and preventing water from remaining in place to sink into soils or to run off the land, causing floods and often carrying valuable topsoil with it. Furthermore, water systems have been engineered to move water away from its source to the oceans with the growing use of water as a means to dispose of farming, industrial and human wastes. As a result, less water returns to continents from the oceans than is lost from continents to oceans, which leads to desiccation of soils, severe drought, wildfires, desertification, and a measure of sea-level rise. There is a growing understanding that these phenomena, often attributed to climate change, may in fact also be a function of disrupted water cycles.

Heat from the sun drives these earthly water cycles. Small water cycles are local, circulating water within a relatively small area. Latent heat causes water to evaporate; heat is absorbed in the process of evaporating water and does not result in an increase in temperature. We do not experience latent heat as an increase in temperature. However, when there is less water available for evaporation, less solar energy is transformed into latent heat and more solar energy is transformed into sensible heat, heat you can feel as increased temperature. This is the heat that we are increasingly experiencing as global warming.

A great deal of heat is moved from the surface of the earth to the upper atmosphere by evaporation and transpiration of water by plants, contributing to significant cooling of the biosphere - to illustrate it takes 540 calories to turn 1 gram of water to vapor; by comparison it takes only 80 calories to melt 1 gram of ice.

Draining of land, that is, runoff and floods, can be reversed through comprehensive conservation of rainwater which maintains the sponge-like absorption capacity of soils and maintains many aspects of soil health, resilience, biodiversity and productivity. Renewal of small water cycles over land can temper extreme weather events and ensure a growth in water reserves by eliminating heat islands and problematic distribution of atmospheric moisture.

Nobre 2010. Antonio Nobre is an Amazon scientist who has studied the biotic pump (see also Makarieva), and tells how he was once told by an indigenous wise man,

> “Doesn't the white man know that, if he destroys the forest, there will be no more rain? And that if there's no more rain, there will be nothing to drink, or to eat?" I heard that . . . [and thought], "Oh, my! I've been studying this for 20 years, with a super computer;

> dozens, thousands of scientists, and we are starting to get to this conclusion, which he already knows!" A critical point is the Yanomami have never deforested. How could they know the rain would end? This bugged me and I was befuddled. How could he know that?
>
> Some months later, I met him at another event and said, "Davi, how did you know that if the forest was destroyed, there'd be no more rain?" He replied: "The spirit of the forest told us."

The equatorial region, in general, and the Amazon specifically, is extremely important for the world's climate. It's a powerful engine for evaporation. From a satellite viewpoint, atmospheric water flow can look like a geyser, which is underground water heated by magma transferred into the atmosphere. There are no geysers in the Amazon but trees play the same role. They, like geysers, transfer an enormous amount of water from the ground into the atmosphere.

“There are 600 billion trees in the Amazon forest, 600 billion geysers. That is done with an extraordinary sophistication. They don't need the heat of magma. They use sunlight to do this process. On a typical sunny day in the Amazon a large tree manages to transpire 1,000 liters of water. If we take all of the Amazon, which is a very large area, and add up all the water that is released by transpiration, ‘the sweat of the forest,’ an incredible amount of water is evaporated into the atmosphere: 20 billion metric tons of water per day.”

“This river of vapor that comes up from the forest and goes into the atmosphere is greater than the Amazon River.” The Amazon River itself is the largest river on Earth, it carries one fifth of all the fresh water, it releases 17 billion metric tons of water a day into the Atlantic Ocean, smaller than “the river in the sky.” To evaporate the 20 billion tons of water released by trees it would take 50,000 of the largest hydroelectric plant in the world, Itaipus, which generates 14 GW of electricity, 30% of Brazil’s power. The Amazon does this with no technology, at no cost.

Croplands

Cultivation thus began an ongoing slow ignition of Earth’s largest surficial reservoir of carbon [Amundson 2015: 647].

For 10,000 years, humans have been clearing patches of forest and grassland to plant crops. While clearing land by burning it visibly turns organic carbon into smoky CO_2, plowing or tilling releases carbon by breaking up soil aggregates that mechanically and chemically protect carbon, while also subjecting the soil to erosion. Exposed soil organic carbon is consumed by microbes, and converted to CO_2 through respiration.

“Since tillage-based farming began, most agricultural soils have lost 30% to 75% of their soil organic carbon (SOC), with industrial agriculture accelerating these.” [Teague 2016: 157] “Unless measures are taken to reduce soil erosion, current agricultural practices are unsustainable and are greater sources of GHG emissions than ruminant livestock in these agroecosystems” [Teague et al. 2016: 158]

Modern agriculture compensates for soil carbon loss by abandoning degraded land or using chemical inputs for the nutrients and pest resistance that an otherwise carbon-rich, biologically active soil provides. However, the farming methods that rebuild topsoil without relying on synthetic inputs, while also ameliorating the worst effects of drought, are the same ones that can make agriculture a major sink for atmospheric CO_2. Such methods, which can be used together as a complementary suite of practices, include no-till; cover-cropping; agro-forestry; more complex crop rotations, including integrating livestock grazing; use of compost, manure, and biochar; and use of deeper-rooting plants and perennials.

Reported sequestration rates vary widely, often measuring at or below 1t C/ha/yr (0.4t C/ac/yr), although much higher rates, several reported below, are also reported. Regarding the lower end of the range, it is important to note that samples are commonly taken to a depth of only 30cm, more or less, while significant amounts of carbon sequestration occurs in deeper soil profiles - up to and beyond 1m depth [Follett 2012, Liebig 2008]. Furthermore, many studies measure sequestration rates for one or two soil-building practices, isolating them from additional, potentially mutually reinforcing and synergistic practices. Finally, many studies are conducted on degraded soils because healthy soils are difficult to find - yet the question of quality and biodiversity of soils examined may not even come up.

Indeed, it is possible for soil organic carbon to increase to amounts greater even than under natural, pre-agricultural conditions. A classic example is the Terra Preta soils of the Amazon, “where intensive management and high levels of organic matter additions were practiced over many years, resulting in greatly enhanced soil C” [Paustian 1997]. Similar examples of this exist among today’s ecologically minded farmers, sometimes in anecdotal examples, who actively seek to build soil organic carbon. California Farmer Paul Kaiser, for instance, uses 5-10 times more compost than most farmers, and has built up a thick topsoil containing 10% SOM. Combining a variety of regenerative practices, he also practices no-till, diverse crop rotations, and agroforestry, surrounding his crops with native trees, shrubs and flowers [Oppenheimer 2015].

In conclusion, we argue that future studies need consider the effects of greater ecological intensity and potentially additive interactions that can exist among multiple soil-building practices, rather than continue to pursue measurement of their individual effects. Future research must also measure SOC changes to much greater depths in the soil horizon in order to capture the full benefit of any given practice/s. Both changes would present a more accurate and likely more promising real-world potential for the climate mitigation potential of agriculture.

Agronomic practices for building soil organic carbon

Cover crops

The use of cover crops protects the soil during a time of year when no cash crops are growing and the soil would otherwise be bare. “Cover crops, also named inter-crops or catch crops, are crops that replace bare fallow during winter period and are ploughed under as green manure before sowing of the next main crop.” [Poeplau 2015: 34] Cover crops can also be rolled and crimped or mowed, instead of plowed, in preparation for the main crop.

Using cover crops can reduce erosion, nutrient leaching, and drought stress, add carbon through continued plant cover and growth, as well as increase biodiversity. Leguminous cover crops also fix nitrogen. “In contrast to other organic amendments, a large part of the C input from cover crop is added as roots, which was found to contribute more effectively to the relatively stable carbon pool than aboveground C-input [Poeplau 2015: 38).

Vick 2016. This Montana study demonstrates that leaving farmland fallow “depletes carbon stocks and thereby soil quality,” (Vick 2016: 129) thus illustrating the importance of keeping land continuously covered with living vegetation. In this study, a CO_2 emissions rate of 1.35 tC/ha/yr (0.54 tC/ac/yr) was measured from land left fallow during the 2014 summer growing season; an adjacent field planted in winter wheat (summer 2013) and spring wheat (summer 2014) was a net carbon sink, measuring carbon input from the atmosphere into the soil at ~2 tC/ha/yr (0.8 tC/ac/yr) and ~1 tC/ha/yr (0.4 tC/ac/yr), respectively. Other parts of this study show a dramatic effect on area cooling (2^o C during the summer) as well as increased moisture and rainfall, from the ending the practice of fallowing alone (see Grasslands section).

Pimentel 2011. Arguing for cover crops as an effective way to reduce erosion and conserve nutrients in soil, Pimentel notes that: “Growing cover crops on land before and after a primary crop nearly doubles the quantity of solar energy harvested in the agricultural system per hectare per year. This increased solar energy capture provides additional organic matter, which improves soil quality and productivity.” [Pimentel 2011: 41]

Barthes 2004. A 12-year study in Benin found 1.3t C/ha/yr (0.52 tC/ac/yr) increase in soil organic carbon when leguminous cover crops were planted a month after corn, and remained as a mulch the following year when corn was planted again, thus keeping a continuous cover on the land.

Crop rotation

Crop rotation diversification can enhance pest resistance, nitrogen input (when leguminous crops are added), soil penetration for better water infiltration (when deeper rooting plants are added), and residue input (when crops that produce more biomass are added). The effects on carbon sequestration from increases in crop rotation diversity vary depending on what crops are included. “Crop species can vary significantly in growth patterns, biomass production, water requirements, and decomposition rates, all of which affect net GHG emissions. Therefore, many rotations could be adapted with alternative species or varieties of annual crops to promote soil C sequestration—increasing root and residue biomass, increasing root exudates, or slowing decomposition—or otherwise reduce emissions” [Eagle 2012: 13].

No-till

No-till allows farmers to plant without disturbing the soil, thus protecting it from water and wind erosion, leaving soil aggregates intact, and preventing a flush of oxygen from activating microbial breakdown of organic matter and releasing CO_2. No-till can contribute to climate mitigation both by reducing emissions from the turnover of soil organic matter caused by tillage, and by sequestering carbon, especially in the surface layer (Mangalassery 2015).

Follett 2012. Measured to a depth of 150 cm, no-till continuous maize grown in eastern Nebraska, fertilized with 120 kg/ha of nitrogen and stover left on the field after grain harvest, sequestered 2.6 tC/ha/yr (1 tC/ac/yr). Notably, more than 50% of sequestered carbon was found below 30 cm (1 ft), illustrating that studies failing to sample below this depth (a common practice) risk greatly underestimating sequestration rates.

Liebig 2008. Measured to a depth of 120 cm (4 ft), switchgrass grown for bioenergy at 10 farms across the Great Plains in the United States sequestered 2.9 tC/ha/yr (1.16 tC/ac/yr). Of that, only 1.1 tC/ha/yr (0.44 tC/ac/yr) was found in the first 30 cm (1 ft) depth, with the remainder measured below 30 cm. The authors explain what makes switchgrass effective in carbon sequestration: “Increases in SOC [soil organic carbon] under switchgrass were likely caused by belowground C input from root biomass and rhizodeposition and decreased soil organic matter losses by erosion. Research conducted by ecologist John Weaver and his graduate students over 60 years ago provide ancillary support for increased SOC under switchgrass. Their detailed surveys of prairie grass roots indicated switchgrass to have the deepest root system of all grasses examined, with roots extending to a soil depth of 3m (9 ft). This finding, coupled with observations that prairie grass roots regenerate by replacing dying roots with new, live roots indicates the potential for significant C input to the soil under switchgrass.”

USDA-NRCS Soil Quality Institute 2001. An Alabama study shows the complementarity of multiple soil building practices. No-till was used in combination with a selection of different intensities of crop rotation. “After 9 years under no-till, the soil C levels increased by 9% in the continuous wheat system, 22% in the wheat-soybean system, and 30% in the wheat-soybean-sorghum system. Soil C levels did not increase under conventional tillage, regardless of cropping intensity.”

Perennials

Unlike annual plants, perennials can live several years. Because of their deep (>2m or 6 ft) and extensive root system and longer growing seasons, perennials are likely to sequester carbon better than annual cropping systems [Glover et al 2007].

Follett 2012. In a 9-year eastern Nebraska trial, switchgrass, fertilized with 120 kg/ha (106 lb/ac) N rate and harvested in October/November after a killing frost, sequestered 2 tC/ha/yr (0.8 tC/ac/yr) in samples measured to 150 cm (5 ft) depth. Plots with an earlier harvest – in August – had lower sequestration rates, presumably due to the shortened timeframe for photosynthesis. As for the parallel maize study (discussed above, under no-till), more than 50% of sequestered carbon was found below 30 cm (1 ft) depth.

Agroforestry

Agroforestry is the practice of integrating trees into a cropping system, including alley cropping, windbreaks, riparian buffers, silvopasture, and forest farming [Eagle 2012, Nair 2009]. It is notable among agronomic practices for adding significant amounts of carbon to above-ground biomass, which is often measured separately from soil organic carbon sequestration [Nair 2009]. One of the strengths of agroforestry is its enhancement of an agroecosystem’s functional diversity. “The utilization of the environment by species includes three main components: space, resources, and time. Any species utilizing the same exact combination of these resources as another will be in direct competition which could lead to a reduction in C sequestration. However, if one species differs in utilization of even one of the components, for example light saturation of C3 vs. C4 plants, C sequestration will be enhanced” [Udawatta 2011: 19).

Montagnini & Nair 2004. Tropical smallholder agroforestry can sequester 1.5-3.5t C/ha/yr (0.6-1.4 tC/ac/yr).

Biochar

Biochar is organic matter that has been burned under controlled, low-oxygen conditions for the purpose of adding to the soil for long-term carbon storage and/or enhancing availability of soil nutrients to plants and microbes. Because charred biomass has been observed to persist in the soil for centuries or millennia [Lehmann 2006], biochar is seen as a stable or recalcitrant form of carbon that can be used for climate change mitigation.

Lehmann 2006. The potential impact of biochar, especially when the energy generated in its creation replaces fossil-fuel as an energy source, is large. “Biofuel production using modern biomass can produce a biochar by-product through pyrolysis which results in 30.6 kg C (67.3 lb C) sequestration for each GJ of energy produced. Using published projections on the use of renewable fuels in the year 2100, bio-char sequestration could amount to 5.5–9.5Gt C/yr if this demand for energy was met through pyrolysis, which would exceed current emissions from fossil fuels (5.4Gt C/yr).”

Grasslands

Grasslands have been estimated to cover approximately 40% of global land surface area, approximately 5.25 bn ha (~13 bn ac) [Suttie 2005], except for Greenland and Antarctica [White 2000:12]. Their deep soils are rich repositories of nutrients, especially carbon, and water. Many grasslands are anthropogenic, i.e., resulting from various land management techniques to maintain land for grazing and crop production by humans. Virgin grasslands are increasingly rare, possibly leading to underestimations of their potential positive contribution to productivity, and to carbon and water storage. Grasslands are important repositories of biodiversity, and have significant impacts on weather and climate. Here we review research and articles that indicate soil carbon storage potentials of roughly 13 gigatons per year (the equivalent of 6.5 ppm) were global grasslands managed regeneratively.

Grasslands have long been a rich repository of carbon, both stable and labile. The co-evolution of grasslands with grazing ruminants has contributed to dramatic global cooling over the past 50 million years as a result of significant photosynthetic carbon drawdown into grassland soils [Retallack 2013]. However, since the onset of agriculture ~10,000 years ago with land management techniques that expose soil to air, estimates of up to 537 gigatons of soil carbon have been oxidized to carbon dioxide and other greenhouse gases [Buringh 1984:91]. Even so, soils currently hold as much carbon as plants, atmosphere and ocean waters combined [NASA 2011], and almost surely retain the potential to store enough atmospheric carbon to return to pre-industrial levels.

Recent studies have illustrated some of the possibilities for climate reversal. Typical soil studies examine the first 30 cm (1 ft) of soil depth, but more recent investigations indicate that major soil carbon storage takes place deeper than that, often in a more stable form.

Follett 2012. A USDA study found unexpectedly high quantities of soil organic carbon (SOC) between 30-150 cm (1-5 ft) below the surface, exceeding 2.25 tC/ha/yr (0.9 tC/ac/yr). Ausmus reports that ". . . a 9-year project that evaluated the effects of nitrogen fertilizer and harvest treatments on soil organic carbon sequestration in switchgrass and no-till maize crops managed for biofeedstock production" found that "more than 50 percent of the soil carbon was found between 1 and 5 feet below the soil surface. The average annual increase of soil organic carbon throughout the first 5 feet of subsoil also exceeded 0.9 tons per acre per year" [Ausmus 2014: 4-5]. Of interest were the difficulties the authors faced in getting the study published due to its results being so far from the expected. It was originally published in *Bioenergy Research* in 2012. [Follett 2012].

Liebig 2008. A study of switchgrass for bioenergy found rates of SOC (Soil Organic Carbon) increase of up to 2.75 tC/ha/yr (1.1 tC/ac/yr) when measured to depths of up to 120 cm (4 ft). "In this study, switchgrass significantly affected change in SOC, a parameter known to respond slowly to changes in management in semiarid agro-ecosystems. In addition to the relatively rapid response, change in SOC was detected on working farms, where spatial variation and potential measurement errors can increase the minimum detectable change in SOC over time." [Liebig 2008:221]

"Change in SOC was determined by collecting multiple soil samples in transects across the fields prior to planting switchgrass and again 5 years later after switchgrass had been grown and managed as a bioenergy crop. Harvested aboveground C averaged 2.5± 0.7 Mg C ha −1 over the 5 year study. Across sites, SOC increased significantly at 0–30 cm (P=0.03) and 0–120 cm (P=0.07), with accrual rates of 1.1 and 2.9 Mg C ha −1 year −1 (4.0 and 10.6 Mg CO 2 ha −1 year −1), respectively." [Liebig 2008:215] This indicates the possibilities of chronic underestimation of soil carbon capacity in the many studies which by convention only measure SOC down to 30 cm (1 ft).

Machmuller 2015. On intensively grazed former row-crop agriculture land converted to dairy farms in the Southeastern U.S., Machmuller et al. found many improvements in the sandy soil, including ~1.25 tC/ha/yr (~0.5 tC/ac/yr) sequestration after accounting for ruminant methane emissions. The study "sought to determine how fast and how much soil C accumulates following conversion of row crop agriculture to management-intensive grazed pastures in the southeastern United States. . . . The highest rates of belowground C accumulation occur when land is converted to grassland ecosystems 7–11 ." These intensively grazed managed systems led to an ~75% increase is soil carbon within six years, a "high C accumulation rate [that] stems from year round intensive forage/grazing management techniques on sandy soils with an initially low soil C content due to past conventional-till row crop agriculture. . . . These forage-management techniques are precisely those suggested to increase SOM in pasture systems and when they are applied to soils with degraded SOC content, such as soils in the southeastern United States, rapid C accumulation ensues."

“On the basis of a whole farm C-cycle analysis, C accumulation appears to offset methane emissions during the rapid soil C accumulation phase . . . As the C accumulation rate declines these farms will become net C-emitting—similar to all dairy production—because of ruminant methane emissions. However, the substantial soil-quality benefits of higher organic matter remain and will likely increase the sustainability of dairy production using management-intensive grazing.” The eventual methane emissions may be markedly less than suggested, however, since the report did not consider methane breakdown from methanotrophic bacteria and atmospheric hydroxyl radical oxidation.

The authors conclude “that pasture-based intensively grazed dairy systems may provide a near-term solution for agricultural lands that have experienced soil-C loss from previous management practices. Emerging land uses, such as management-intensive grazing, offer profitable and sustainable solutions to our needs for pairing food production with soil restoration and C sequestration.” [Machmuller 2015: 2-3]

Retallack 2001, 2013. “Grassland expansion initiated increased organic C storage in soils, soil water retention, speed of nutrient exploitation, surface albedo, and C burial in sediments eroded from their soils. These changes had many consequences, including long-term global cooling.” [Retallack 2001:422] and “This climatic zone is not only the most widespread, but also the most fertile region of our planet.” [Retallack 2013:78] The paleohistory of grasslands provides the basis for considering the potential of grasslands as huge biological carbon sinks that may be realized again with regenerative land management

Rodale Institute 2014. Rodale reports that regenerative grazing practiced on a global scale could sequester 71% of annual emissions 14 Gt C/yr. These combined results from regenerative grazing and agriculture techniques alone could, if practiced globally, lead to a net reduction of atmospheric carbon dioxide of 1.7 gigatons per year, or 0.85 ppm/year when added to regenerative agriculture’s contribution sequestering 40% of annual emissions (5.7 Gt C/yr). This results in a potential sequestration of approx. 3t C/ha/yr on grasslands and croplands. [Rodale Institute 2014:9] This does not include the considerable contributions of non-agricultural lands, nor recent developments in intensive regenerative practices such as permaculture and biochar.

There remain many additional restoration opportunities in other ecosystems and approaches that we consider elsewhere in this Compendium.

Rowntree 2016. Examining ruminant methane and net carbon sequestration for grassfed beef in a systems context, Rowntree found net sequestration rates of up to 2.11 tons/ha/yr (0.84 tC/ac/yr) for non-irrigated, lightly stocked grazing [Rowntree 2016].

Teague et al. 2016. In a review of the literature, the authors conclude that regenerative conservation cropping and adaptive multipaddock grazing can turn agricultural soils from a carbon source in conventional agriculture into a carbon sink at rate of ~3 tC/ha/yr (~1.2 tC/ac/yr). Key factors include the use of no-till, cover crops, managed grazing, organic soil amendments and biotic fertilizer formulations. These practices can result in elimination of soil erosion and loss, the greatest agricultural contribution to global warming (1 Gt/C/yr). Benefits may include "increased water infiltration, improved water catchment, greater biodiversity, increased ecosystem stability and resilience, and improved C sequestration." [Teague 2016:158]

Vick et al. 2016 observed that a widespread decline of land left fallow in agricultural areas of the Canadian Prairie Provinces coincided with a summertime cooling trend since the 1970s. They noted that extreme temperature events now occur less frequently than in the recent past, maximum summer temperatures have decreased by ca. 2° C (3.6° F), relative humidity has increased by some 7% and summer precipitation has increased by an average of 10 mm/decade across parts of the Canadian Prairie Provinces. A remarkable 6 W/m^2 summer cooling has been observed compared to a ca. 2.5 W/m^2 warming globally since the dawn of the Industrial Era.

Finally, it is worth noting that there may be a significant underestimation of surface area and volume of soils in grasslands, as well as in other ecosystems, since natural topographies are not uniformly flat. Topographical variations would add volumes of soil carbon, water, etc. to prior estimates of areas that are typically calculated on the basis of a two-dimensional map projections [Blakemore 2016: Fig. 5]. The implications are that there may be considerably greater volumes of soil amenable to regenerative management, carbon capture and water storage than is conventionally assumed. Such adjustments to soil volume calculations would positively affect carbon drawdown estimates in considering the potentials of eco-restoration in climate.

Conclusion

These reports demonstrate the potential for massive amounts of soil carbon storage along with dramatic improvements in ecosystem health using regenerative approaches to grassland management.

Forests

Ellison 2016. Many forests and forested areas have diminished significantly in size due to deforestation. It is imperative to establish the connection between reforestation goals, water cycle restoration goals, and climate change reversal goals. Forests are inherently linked to water availability and rainfall, through their presence in the small water cycle and their involvement in the evapotranspirative process. Cloud formation has also been linked to forested areas, with the condensation of moisture and ice nucleation forming on airborne aerosol particles dispersed by trees. Air over tropical forests produces twice as much rain as air passing over sparse vegetation. Mixed species forests are healthier, more productive, and more resilient than monocultures. Surface albedo, surface roughness, temperature, and evapotranspiration all affect the moisture and heat fluxes between the ground and atmosphere; thus, trees, and furthermore forests, play vital roles in the water and thermic cycles.

Humans and all living species are adapted to the environmental conditions of the Holocene period. Carbon storage, cooling terrestrial surfaces, and distribution of water resources are founded on forest, water, and energy interactions. [Ellison 2016: 51] Thus, hydrologic and climate-cooling effects of trees and forests should be prioritized alongside their ability to store carbon. In actions impacting climate change, carbon storage and water resources must be considered simultaneously and equally.

Forests provide precipitation cycling, cooling, water purification, infiltration and groundwater recharge, food/fuel, and carbon storage. If conducted correctly, restoration can improve water availability and balance in the water-energy cycle; however, improper restorative techniques (i.e. use of exotic species, plantation forests) may disrupt evapotranspiration system and/or water availability.

While there exists more uncertainty in the levels of carbon emissions associated with deforestation, it is certain that deforestation is contributing to carbon emissions, and, thus, current atmospheric carbon levels. Reliable access to water and tolerable atmospheric temperatures are stable ingredients of life, and water and energy cycle feedbacks must be included in reforestation goals. With a goal of mitigating an approximate 100 GtC of deforestation emissions, atmospheric carbon levels could be improved by increased soil storage, via reforestation and better agriculture/forestry practices. [Ellison 2016]

Makarieva 2007. Forests transport water and moderate temperatures on both the local and global scale. They capture fog, mist, and clouds and redistribute the water to the surface below. While forests help cloud formation, they also help cloud movement as well. The biotic pump theory suggests that forests create low pressure regions (via transpiration and condensation) that pull moist air in from the ocean. These low pressure regions generate wind; rainfall over inner-continental land is driven and maintained by these winds, which cause atmospheric circulation. [Makarieva 2007]

APPENDIX A

The Advancement of Science: From Paradigms to Peer Review

Paradigms and How They Shift

Understanding the role of paradigms in scientific investigation is one of the keys to approaching the revolutionary view of climate as a problem of ecosystem dynamics as opposed to one simply of excessive greenhouse gases. The new paradigm doesn't render the old paradigm irrelevant, but it reframes its significance and role in addressing the current climate crisis. It exposes to open examination what was heretofore an invisible phenomenon, and avails a universe of solutions to what is, from the perspective of the greenhouse gas hypothesis, an intractable and quite possibly utterly hopeless problem. Therefore, we will take a moment to review the paradigm process and apply it to our contending climate paradigms.

In 1962, Thomas Kuhn, a Harvard-trained physicist who became a historian and philosopher of science, published a controversial book, *The Structure of Scientific Revolutions*. Prior to Kuhn, the prevailing assumptions about the way science progressed were that knowledge was gradually accumulated by generations of investigators, with occasional quantum leaps by great scientists, but in an overall smooth and continuous albeit occasionally heroic process.

Kuhn broke new ground by re-examining and reframing the process of scientific investigation. He brought the term "paradigm" into common usage, by which he meant a body of "universally recognized scientific achievements that *for a time* provide model problems and solutions to a community of practitioners" (p. viii, emphasis added). We will review Kuhn's work briefly and apply his analysis when comparing the mainstream greenhouse gas climate paradigm and the newly evolving eco-restoration climate paradigm.

Kuhn maintained that scientific progress is episodic, characterized by long periods of "normal science," which takes place in the context of a paradigm:

> At least in the mature sciences, answers (or full substitutes for answers) to [many] questions . . . are firmly embedded in the educational initiation that prepares and licenses the student for professional practice. Because that education is both rigorous and rigid, these answers come to exert a deep hold on the scientific mind. [Kuhn 1962:5]
>
> Normal science, the activity in which most scientists inevitably spend almost all their time, is predicated on the assumption that the scientific community knows what the world is like. Much of the success of the enterprise derives from the community's willingness to

> defend that assumption, if necessary at considerable cost. Normal science, for example, often suppresses fundamental novelties because they are necessarily subversive of its basic commitments. Nevertheless, so long as those commitments retain an element of the arbitrary, the very nature of normal research ensures that novelty shall not be suppressed for very long. [Kuhn 1962:5]

Normal science is punctuated by the appearance of anomalies which cannot be explained by the paradigm's generally accepted theories, nor tested by what the paradigm might consider reasonable hypotheses, nor resolved with current testing protocols or equipment.

> When examining normal science . . . we shall want finally to describe that research as a strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education. [Kuhn 1962:5]

> [W]hen [normal science repeatedly goes astray] — when, that is, the profession can no longer evade anomalies that subvert the existing tradition of scientific practice—then begin the extraordinary investigations that lead the profession at last to a new set of commitments, a new basis for the practice of science. The extraordinary episodes in which that shift of professional commitments occurs are the ones known in this essay as scientific revolutions. They are the tradition-shattering complements to the tradition-bound activity of normal science. [Kuhn 1962: 6]

and

> Normal science consists in . . . an actualization achieved by extending the knowledge of those facts that the paradigm displays as particularly revealing, by increasing the extent of the match between those facts and the paradigm's predictions, and by further articulation of the paradigm itself.
>
> Few people who are not actually practitioners of a mature science realize how much mop-up work of this sort a paradigm leaves to be done or quite how fascinating such work can prove in the execution. And these points need to be understood. Mopping-up operations are what engage most scientists throughout their careers. They constitute what I am here calling normal science. Closely examined, whether historically or in the contemporary laboratory, *that enterprise seems an attempt to force nature into the preformed and relatively inflexible box that the paradigm supplies*. No part of the aim of normal science is to call forth new sorts of phenomena; indeed those that will not fit the box are often not seen at all. Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others. Instead, normal-scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies. [Kuhn 1962:23-24, emphasis added]

and

> Paradigms gain their status because they are more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute. *To be more successful is not, however, to be either completely successful with a single problem or notably successful with any large number.* The success of a paradigm . . . is at the start largely a promise of success discoverable in selected and still incomplete examples. [Kuhn 1962:23, emphasis added]

Even today, over half a century after *Structures* was originally published, normal science seems immune to the possibilities of paradigm shifts - such thoughts often do not occur until forced, even though the process should be reasonably well known if not entirely understood or accepted. The prevailing opinion about paradigm shifts (if there is any opinion at all) appears to be, “It doesn’t apply to *my* paradigm.”

In general, a paradigm shift doesn’t only involve “objective” factors, it touches scientific practitioners at a deep emotional level as well, as any participant in or observer of academic dispute can testify:

> Scientific fact and theory are not categorically separable, except perhaps within a single tradition of normal-scientific practice. That is why the unexpected discovery is not simply factual in its import and why the scientist’s world is qualitatively transformed as well as quantitatively enriched by fundamental novelties of either fact or theory. [Kuhn 1962:7]

Therefore, the transition to a new paradigm is disruptive and challenging:

> The transition from a paradigm in crisis to a new one from which a new tradition of normal science can emerge is far from a cumulative process, one achieved by an articulation or extension of the old paradigm. Rather it is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field’s most elementary theoretical generalizations as well as many of its paradigm methods and applications. During the transition period there will be a large but never complete overlap between the problems that can be solved by the old and by the new paradigm. But there will also be a decisive difference in the modes of solution. When the transition is complete, the profession will have changed its view of the field, its methods, and its goals [Kuhn 1962:84-85].

The case in point here is the comparison between old and new climate paradigms

Paradigm step	Old paradigm (greenhouse gas)	New paradigm (Eco-restoration)
Paradigm fundamentals	CO_2 and equiv are greenhouse gas blankets and elevated levels cause global warming, primarily caused by burning fossil fuels	Destruction of billions of acres of land and NPP interfere with carbon and water cycles, along with oxidation of soils for over 10k years, puts gigatons of carbon into atmosphere
Errors intrinsic to paradigm	Positive feedbacks underrepresented, overlooked, not calculated or estimated; biology is characterized as passive victim of climate change	Complex, interdependent systems that are difficult to model and to quantify into policy
Strengths intrinsic to paradigm	Amenable to modeling; yields numeric targets that can be translated into policy	Comprehensive of all likely drivers and their theoretical interdependences. Plausible upon examination of biogeologic history.
Primary investigators	Physical scientists almost exclusively from academia	Restoration ecologists and others from biological sciences; non-academic land managers
Tools	Emissions reductions via alternative energy and elimination of carbon emissions sources	Photosynthesis and regenerative land management
Costs	High	Low
Technology requirements	Extensive	Minimal
Locus of investigation	Centralized in academia - universities, scientific journals, formal test sites	Based first in local land management practice, then investigated by academia, landscape managers, local practitioners - farmers, ranchers, horticulturalists, permaculturists, indigenous cultures, etc.
Weight of evidence	Formal studies, isolated variables	Practical results, holistic assessment of land health, biodiversity, water and carbon cycling

Success criteria	Reduced emissions and atmospheric carbon burdens (target 350 ppm? lower?)	Increased biodiversity, improved water cycles, land resilience, cooling of local biospheres on a global scale, reduced floods and droughts, decline in atmospheric carbon burdens (target 280 ppm)
Duration of existence of paradigm	Roughly 200 years	Roughly 20 years with some roots going back considerably longer

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