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Soil Restoration, Ocean Anoxia, & Menhaden Reduction – New Considerations for Climate Change Dynamics and Mitigation

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Abstract

There are three emerging areas of research that we believe hold promise for helping to understand and mitigate the impacts of climate change. Although they stem from diverse fields of inquiry, we believe their effects are tightly coupled. These concern the following: (1) the role of soils in climate stability and their potential for significant, permanent, and viable carbon sequestration of up to 10 gigatons per year, (2) the role of ocean anoxia as a predecessor to extinction episodes, and its troubling rise in today's seas, and (3) the role of algae eating fish, such as menhaden, in controlling estuary eutrophication and rapid expanse of ocean "dead zones". Seen together, these three areas of research show that restoring degraded soils while putting a moratorium on the fishing of algae eaters, may in fact be the most efficient way to reduce atmospheric CO2 to below dangerous levels (350 ppm) while avoiding perilous trigger events, such as ocean anoxia. These measures can be achieved without great sacrifice or cost, and in a fashion that supports improved yields, reduced environmental impacts, and new sustainable economies.

1. Soil Restoration – The Great Untold Story for Carbon Sequestration

The foremost factor for consideration is the role of soils in climate stability and carbon sequestration. This may be our greatest asset in the fight against global warming as soils are the largest sink we know how to manage. The worldwide carbon concentration in soils is commonly estimated at between 1500 and 2400 gigatons. This is 8 to 13-times the amount of excess carbon in our atmosphere (estimated at 180 gigatons or the equivalent of 90 ppm). The richest soil ecosystem for carbon sequestration is grasslands or "prairies" where carbon concentration can exceed 100 tons per acre. When Lewis and Clark crossed the North

American Prairie, they were walking on one of the word's largest stores of organic carbon. Grasslands spanned over 600 hundred million acres across the continental interior from central Canada to the Mexican border. The carbon was sequestered through the action of billions of prairie dogs and tens of millions of buffalo and other herding grazers that helped the grasslands stay moist, aerated, and teaming with subterranean biodiversity. Unfortunately, this store has been robbed and prodigious amounts of carbon have been released into the atmosphere or washed away with topsoil into rivers, bays, and estuaries. Estimates of organic carbon loss in agricultural soils worldwide are commonly 50 to 80% (Rice 2002, Jones 2006a, O'Grady 2007). The USDA estimates (conservatively we believe) that 40% of native soil carbon in the United States has been lost. Fortunately, carbon lost from soils can be reacquired through soil restoration.

Rising to the occasion, a growing community of scientists and farmers is investigating and harnessing the potential. Key among these is Allan Savory of Holistic Management International in New Mexico, Paul Hepperly of The Rodale Institute in Pennsylvania, and Allan Yeomans of Yeomans Plow Company in Australia. Their research demonstrates that soil restoration holds great promise for massive, quick and permanent carbon sequestration of the magnitudes necessary to reverse CO2 buildup and bring us back 350 ppm or lower within a time frame necessary to avoid catastrophic climate change. Allan Savory's group is demonstrating carbon sequestration levels of 1 ton/acre/year in rangeland environments of the American Southwest that had all but turned to desert (Savory & Peck 2007). They are doing this, counter intuitively, by *increasing* the number of cattle, yet moving them according to a grazing plan that imitates natural herd behavior. This process recognizes that animal impact is essential to soil health in prairie ecosystems (Savory & Butterfield 1998). Hepperly's group is demonstrating soil sequestration of 2 tons/acre/year on croplands soils using a combination of innovations such as cover crops and crop rotation (Hepperly & LaSalle 2008), and Yeomans is pioneering the Keyline process of non-till irrigation, which in creating fertile soils in Australia (Yeomans 2007). In addition to these scientific investigations, numerous independent citizen and farming groups are forming. These include Carbon Farmers of America, Managing Wholes, and The Soil Carbon Coalition.

Given the success of these demonstration projects, it is easy to understand the mounting enthusiasm for soil restoration as a climate stabilizing mechanism. Soil restoration of the types mentioned above, applied to the approximately 10 billion acres of suitable land worldwide can sequester 10 gigatons per year. That is 100 gigatons within a decade representing a reduction of 50 ppm atmospheric CO2. No other sequestration methodology can make that claim. If we could switch to sustainable energy and begin restoring soils tomorrow, we could draw down atmospheric CO2 concentrations to 335 ppm by 2020. Perhaps even more encouraging is the fact that this massive carbon sink represents only a small fraction of the total potential. Australian soil biologist Christine Jones has demonstrated that just a 1% increase in soil organic matter can sequester approximately 10 tons of carbon per acre (Jones 2006b). Yeomans calculates just a 1.6% increase worldwide could sequester the entire burden of excess atmospheric carbon dioxide. Savory believes that through soil restoration efforts, our excess atmospheric carbon can be absorbed within 15 years. O'Grady & Rush (2007) calculate that we could achieve carbon neutrality through a restoration of merely 10% of degraded soils. The Rodale Institute is similarly optimistic. In any case, we are talking about massive quantities in short time spans. These are the measures necessary to protect a sustainable future. The added benefits of soil restoration is that it increases land productively and resiliency to drought, helps prevent runoff, and provides new, non-fossil fuel intensive economic opportunities for small farmers. It is arguable that the most effective climate change policy could simply be to revise farm bills that currently encourage soil loss, and instead provide incentives for soil replenishment, and hence, carbon capture. As the Rodale Institute states:

> *"Agriculture is an undervalued and underestimated climate change tool that could be one of the most powerful strategies in the fight against global warming. Nearly 30 years of Rodale Institute soil carbon data show conclusively that improved global terrestrial stewardship--that specifically includes 21st Century regenerative agricultural practices--can be the most effective currently available strategy for mitigating CO2 emissions." (*Hepperly & LaSalle 2008)

We believe the time has come for the climate change community to take a closer look at the role of soils in our efforts to halt global warming.

2. CO2, Ocean Anoxia & Extinction Episodes - Terror From the Deep

The second new factor concerns the role of greenhouse conditions in extinction events, and particularly, and troubling so, the accompanying anoxification of oceans and worldwide profusion of hydrogen sulfide gas. This represents a new understanding in paleontology with shocking implications for contemporary climate science. Dr. Peter Ward, a paleontologist at the University of Washington, has helped bring these findings to light in his 2007 book, *Under a Green Sky: Global Warming,* *the Mass Extinctions of the Past, and What They Can Tell Us About Our Future*. As Ward explains, using recently developed biomarker analysis, it has been shown that CO2 spikes accompanied all but one of the major extinction events (Figure 1). These include the ancient Cambrian Extinction, the more recent Paleocene Extinction, and of course, the mother of all extinctions, the Permian, approximately 250 million years ago, when 95 percent of life vanished. Of these, and not surprisingly, the Permian spike is the most dramatic. Atmospheric CO2 levels shot up 10-fold from roughly 300 to 3000 ppm in a 20 million years. These CO2 spikes were probably caused by volcanic activity and helped contribute to atmospheric warming, yet such conditions on their own could not have accounted for the mass extinctions. Something more sinister was in play, and it wasn't meteorites.

The resolution of the mystery, according to Ward, came in 2005 when two scientific papers changed forever our understanding of extinction episodes. What has been revealed is that at least three of the largest extinction episodes, including the Permian, were caused by a worldwide profusion of hydrogen sulfide gas emanating from anoxic oceans that were triggered by greenhouse conditions. The oceans of the earth were basically turned to stagnant rotten egg smelling swamps and massive die-offs happened from the bottom up as deep anoxic zones gradually rose to the surface. Although the asteroid impact that killed the dinosaurs is popularized as a template for extinctions, it is actually the exception. The more common culprit is climate change triggered ocean anoxia.

As Ward explains it, the greenhouse conditions disrupt the conveyor currents forcing ocean bottoms to fill with warm poorly oxygenated water. The melting of polar ice and decreases of equator-to-pole temperature gradients diminishes surface winds and currents. Oxygen mixing comes to a halt and anoxia follows. These conditions, though trouble for us, are ideal for Earth's earliest life forms - sulfur oxidizing bacteria. During periods of ocean anoxia, these creatures from the Precambrian era once again reign supreme, emitting copious amounts of hydrogen sulfide gas and killing countless species in the process. Indeed, as Ward writes in an essay for New Scientist, *The Pre-Cambrian Strikes Back*, extinction episodes are in many ways a tug of war between these two basic forms of life - those that do and those that don't thrive in the presence of oxygen (Ward 2008). Extreme greenhouse conditions invariably favor the latter - the success of which drives the extinction of the former. This, in Ward's view, is the pattern of extinction episodes - they are the legacy of CO2 induced climate change.

The papers that Ward considers seminal in revealing this startling fact of extinction episodes are by Roger Summons et al from MIT (Summons

2005) and Lee Kump et al from Penn State (Kump 2005). The Summons paper, *Photic Zone Euxinia During the Permian-Triassic Superanoxic Event,* reports on biomarker analysis that shows that a rare species of green sulfur bacteria, Chlorobiaceae, is prolific during the Permian extinction episode. This species, however, can only exist in extremely unusual conditions: It must be in surface waters where light can penetrate (a "photic zone"), it cannot be in the presence of oxygen, and it requires an ample supply of hydrogen sulfide. The Summons paper concludes that due to the predominance of this bacteria, enormous quantities of hydrogen sulfide gas must have been present in surface waters and, further, that the accumulation of this gas was sufficient to be a key factor in the massive die-offs. They write:

> *"The data show that PZE (photic zone euxinia) conditions occurred during the P-T (Permian-Triassic) superanoxic event and document a major disruption of the carbon and sulfur cycles....we propose that sulfide toxicity in the ocean and emission of hydrogen sulfide to the atmosphere were important drivers of the largest mass extinction in the past 500 million years and may have also been a factor in the protracted recovery."* (Summons et al 2005)

The second seminal paper, according to Ward, by Kump et al, is titled *Massive Release of Hydrogen Sulfide to the Surface Ocean and Atmosphere During Intervals of Oceanic Anoxia.* The Kump team uses ocean circulation models to show that past greenhouse conditions could have altered paleooceans to the extent that hydrogen sulfide emissions to the atmosphere would have exceeded today's level by 2000 times, becoming an undeniable factor in the demise of life. Even more troubling, Kump finds that there is a threshold level of hydrogen sulfide in the oceans, above which the "chemocline" - or boundary between the sulfur zone and oxygen zone - can suddenly change. This newly discovered vulnerability would permit the normally deep sulfur zone to rapidly reach surface, bringing its toxic wake with it. As if climate change dynamics didn't already have enough "tipping points", now we have another. Kump writes:

> *"Simple calculations show that if deep-water H_2S (hydrogen sulfide) concentrations increased beyond a critical threshold during oceanic anoxic intervals of Earth history, the chemocline separating sulfidic deep waters from oxygenated surface waters could have risen abruptly to the ocean surface (a chemocline upward excursion). Atmospheric photochemical modeling indicates that resulting fluxes of H_2S to the atmosphere (>2000 times the small modern flux from volcanoes) would likely have led to toxic levels of H_2S in the atmosphere. Moreover, the ozone shield would have been*

destroyed, and methane levels would have risen to >100 ppm. We thus propose (1) chemocline upward excursion as a kill mechanism during the end-Permian, Late Devonian, and Cenomanian-Turonian extinctions, and (2) persistently high atmospheric H_2S levels as a factor that impeded evolution of eukaryotic life on land during the Proterozoic." (Kump et al 2005)

A subsequent paper by Meyer and Kump (2008) reveals yet another troublesome dynamic. As oceans become anoxic they dissolve sedimentary phosphate. This increases the oxygen demand through biotic action, which, in turn, further spreads the anoxia. Thus, a positive, and deadly, feedback is established.

> *"We conclude that periods of global warmth promoted anoxia because of reduced solubility of oxygen...Anoxia led to phosphate release from sediments, and continental configurations…This great nutrient supply would have fueled high biological productivity and oxygen demand, enhancing oxygen depletion and sulfide buildup via sulfate reduction. As long as warm conditions prevailed, these positive feedbacks sustained euxinic conditions." (Meyer and Kump 2008)*

Given the twin findings of the Summons and Kump teams, the implications are ominous. They raise the specter of a yet unheralded disaster hiding in the deep and are a wakeup call for understanding the full potential impacts of greenhouse conditions and ocean anoxia. Ward is emphatic in his warning and we echo his call. As concerned as we should be about ocean acidification, it is anoxia that holds the greatest threat - the Lucifer Hammer, if you will, of extinction. Unfortunately, the conditions that led to the fall of this hammer in previous extinction episodes are similar to what is happening now: a CO2 spike and warming oceans coupled with the spread of dead zones.

3. The Decline of Menhaden - The Fish That Safeguards The Future

The third factor is the population decimation of the most abundantly caught fish in America waters, menhaden, an algae eater whose role in estuary ecology is only recently understood. A 2007 book by Bruce Franklin, *The Most Important Fish in the Sea: Menhaden and America*, helps elevate this fish to its proper standing. Long sought as an industrial product for oil, fertilizer and animal feed, the menhaden is becoming recognized as the signature species in the purification of nutrient rich coastal waters and the prevention of eutrophication and subsequent spread of dead zones. A single adult menhaden can filter 4 gallons of water per minute. In pre-colonial times, menhaden populations jammed the estuaries up and down the eastern United States and Gulf of Mexico, cleaning the waters while providing an abundant food source for countless predatory fish, such as cod, blue fish, and mackerel. Speaking of the role of menhaden in estuary ecology, Franklin writes:

> *"Dense schools or menhaden, sometimes numbering in the hundreds of thousands, pour through these waters, toothless mouths agape, slurping up plankton, cellulose, and just plain detritus like a colossal submarine vacuum cleaner as wide as a city block and as deep as a train tunnel...this filter feeding clarifies the water, allowing sunlight to penetrate. This in turn encourages the growth of aquatic plants that release dissolved oxygen while also harboring a host of fish and shellfish." (Franklin 2007, pp8)*

Unfortunately, the near demise of the menhaden is being coupled with both a rapid increase in nutrient rich runoff and warming waters - a lethal cocktail for ocean anoxia. Speaking to this scenario, Franklin continues:

> *"This can generate deadly blooms of algae, such as red tide and brown tide, which cause massive fish fills, then sink in thick carpets to the bottom, where they smother plants and shellfish, suck dissolved oxygen from the water, and leave dead zones that expand year by year." (Franklin 2007, pp8)*

Nowhere is this scenario played out more vividly than in the Gulf of Mexico and Chesapeake Bay, where massive nutrient runoffs and over fishing of menhaden are accompanied by both growing dead zones and warming waters. According to a recent NOAA-supported study (NOAA 2008), the annual survey of Gulf waters has detected a "dead zone" larger than the state of Massachusetts. At just under 8000 square miles, it is the second largest since observations began in 1985. NOAA defines a dead zone as areas where "oxygen levels drop too low to support most life in bottom and near-bottom waters". And in the Chesapeake Bay, a landmark study of 52 years worth of dissolved oxygen levels found areas of "sever hypoxia" more than quadrupled from 1.6 to 6.5 billion cubic meters (Hagy 2008). Severe hypoxia refers to dissolved oxygen levels lower than 1.0 milligram per liter. Such sparse oxygen is lethal even to crabs and worms. During this same period, there emerged, something even worse. For the first time in record in the Chesapeake Bay, areas of complete oxygen loss (anoxia) were detected, from none in 1950 to over 3.6 billion cubic meters by 2001. According to the Chesapeake Bay Foundation (cbf.org), the various levels of oxygen depletion effected 40% of the Bay's main stem, extending more than 100 miles.

A doomsday scenario whereby the Chesapeake Bay and Gulf of Mexico become anoxic hydrogen sulfide emitting swamps is neither without reason nor precedent. Every year they further resemble the shallow toxic seas of the late Permian. Ironically, much of the nutrient rich runoff is coming from soil loss that is further exacerbating global warming and much of the menhaden catch is going to industrial feedlots the runoff from which is fueling noxious algae blooms. Franklin points to the fact that the onset of reoccurring dead zones in the Gulf of Mexico began exactly during the period of peak menhaden catches (approximately 11 billion fish per year between from the late 1960s to early 1980s). As he writes:

> *"It would be difficult to argue that annihilating many billions of menhaden has been a primary cause of algal blooms and the recurring dead zone. It would be more difficult to argue, however, that killing tens of billions of menhaden did not remove a significant check on those algal blooms and the growth of dead zones." (Franklin 2007, pp164)*

The problem with soil loss, menhaden reduction, and algae blooms is a vicious cycle. The only way to counter it is to couple revised farming practices with a moratorium on menhaden fishing. The threats of coastal hypoxia would be kept in check while an essential food for larger fish would be preserved.

Future Considerations & Trigger Events – Rising Seas in Low Lying Areas, Such as Florida and the Gulf Cost, Submerges Rich Soils and adds Massive Nutrient Loads to Shallow Coastal Waters

The climate change community is correct in pointing out the immediate impact of rising sea levels to coastal habitation, however, there is a subsequent and potentially more troubling consequence – rapid nutrient loading. The same sea level increase that pushes people inland, also submerges nutrient rich soils. In extremely low lying areas, such as the Gulf Coast, the Bay of Bengal, and the Nile Delta, this massive nutrient increase to shallow warm water spells disaster. These flooded regions could turn quickly anoxic. If it isn't bad enough that we are dumping our soils from the heartland into the sea, now, in a greenhouse scenario, the sea is rearing up to swallow soils on its own. Scenarios that paint much of Florida and the Gulf Coast underwater, adequately spell warning to the destruction of coastal cities and the numerous social consequences that would unfold. However, they say nothing of the profound impact that the nutrient load may have on a Gulf system that is already warming and becoming dangerously anoxic. Given what Kump has shown about the rapid "upward excursion" of sulfidic zones and the positive feedback cycle of nutrient loading and ocean anoxia, we must realize that if rising seas consume low lying areas, human relocation will be the least of our problems.

Conclusion - Promise and Warning

We see both promise and warning in the mentioned findings that warrant attention of the climate change community. First and foremost is the role of soils. Their potential for climate change mitigation is likely greater than has been appreciated. If we want to reduce atmospheric CO2 to 350 ppm or lower, we are going to need a prodigious sink that can be harnessed quickly. Soil restoration is the answer. The work of Savory and others indicates that only a slight increase in soil organic matter worldwide could greatly offset our carbon load. Sequestration levels of 10 GT/yr are within our reach. It can be accomplished through natural methods while satisfying commercial interests. Secondly, is the finding that throughout most of earth's history, extinction episodes have been the consequence of greenhouse triggered ocean anoxia. This poses yet another risk to our future as oceans warm, dead zones spread, and rising seas threaten to submerge low lying and nutrient rich coastal areas. Although there is no upside to this finding, it provides an essential framework from which to understand our current predicament. Third, and finally, is the role of menhaden and other algae eaters in controlling the health of coastal waters. In the light of what we know understand about ocean anoxia, their service and the threat of their demise can't be over emphasized. Of course the menhaden issue, in many respects, is the flip side of the soil issue. The algae blooms are caused firstly by excess nutrient loading, but then exacerbated by the lack of any controlling mechanism. The promise is that menhaden populations, like soil carbon, can be quickly restored.

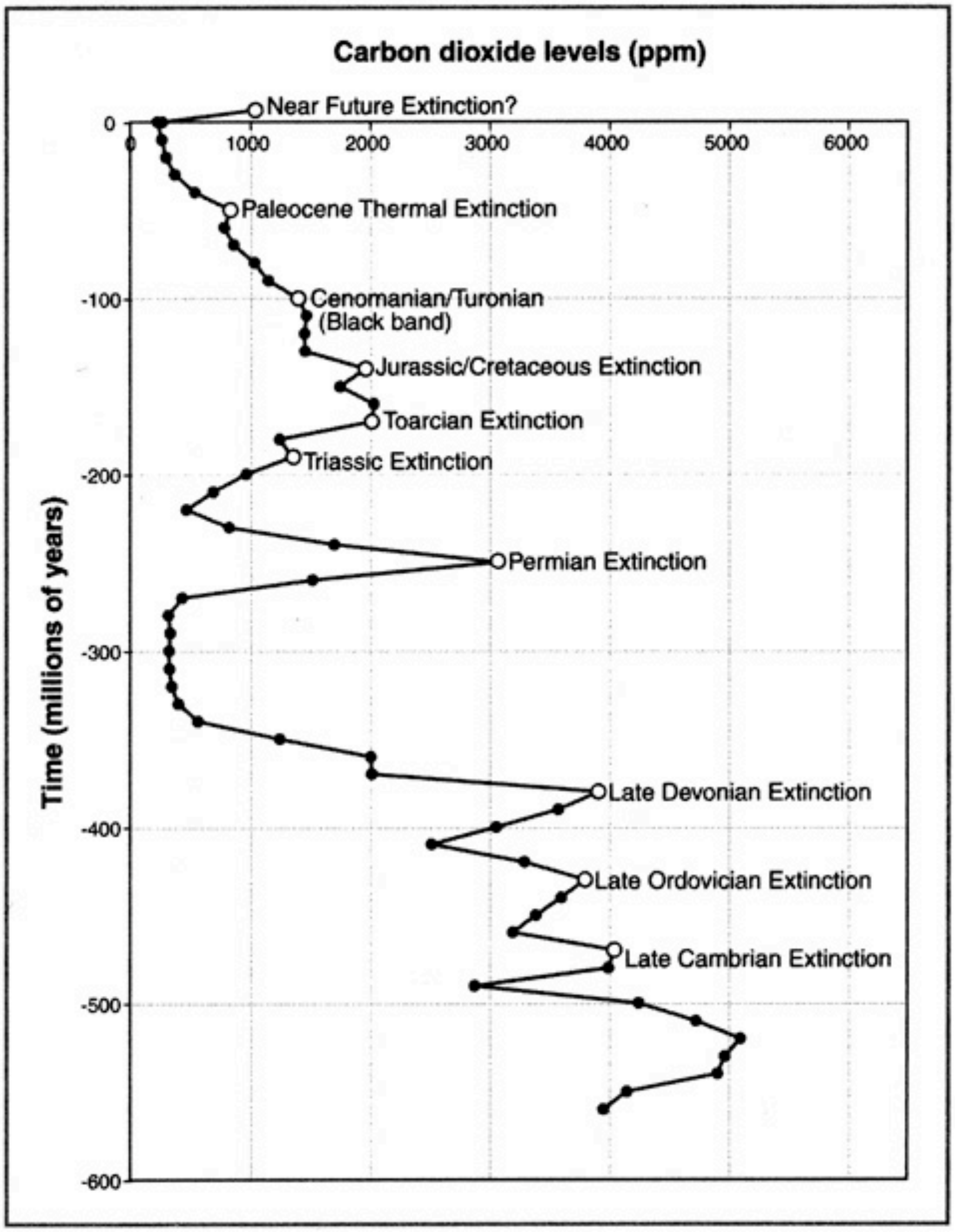

Figure 1: "Driver of Extinction": Atmospheric CO2 - 550 Million Years Ago to Present.
Source: Ward, Peter (2007). *Under a Green Sky: Global Warming, the Mass Extinctions of the Past, and What They Can Tell Us About Our Future*. HarperCollins, NY 2007, p 135.

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