Savory

RESTORING THE CLIMATE THROUGH CAPTURE AND STORAGE OF SOIL CARBON THROUGH HOLISTIC PLANNED GRAZING

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ABSTRACT

The quantity of carbon contained in soils is directly related to the diversity and health of soil life. All organic carbon sequestered in soils is extracted from the atmosphere by photosynthesis and converted to complex molecules by bacteria and fungi in synergy with insects and animals. An effective, profitable, and culturally relevant method for increasing soil organic carbon is to restore grasslands worldwide to their optimal health. To accomplish this at the scale and pace that we need, Holistic Management and one of its associated processes, Holistic Planned Grazing offers us a tangible way to restore the climate by properly managing livestock to build soil life. Since the 1970s Holistic Management's effectiveness has been well documented on millions of hectares on four continents. By restoring grasslands through Holistic Planned Grazing we have the potential to remove the excess atmospheric carbon that has been the result of both anthropogenic soil loss over the past 10,000 years and industrial-era greenhouse gas emissions. This sequestration potential, when applied to up to 5 billion hectares of degraded grassland soils, could return 10 or more gigatons of excess atmospheric carbon to the terrestrial sink annually thereby lowering greenhouse gas concentrations to pre-industrial levels in a matter of decades. This while restoring agriculture productivity, providing jobs for thousands of people in rural communities, supplying high quality protein for millions, and enhancing wildlife habitat and water resources.

Holistic Planned Grazing in practice: Northern Great Plains, United States.
Photo by David Nicola.

INTRODUCTION

The future challenges to humankind are considerable, with climate change at the top of the list. It is projected that food production, which is entirely dependent on a benign climate, will have to increase by 50% by 2050 to keep pace with global population needs (Millennium Ecosystem Assessment, 2005).

High intensity agriculture is heavily dependent on fossil fuel energy imports and irrigation, as shown on this former grassland in Oregon, United States.

Our ability to produce more food has increased dramatically in the latter half of the past century because of technological innovation driven by cheap fossil fuels (Janzen, 2011). However, this increased productivity has resulted in substantial damage to the ecosystem upon which we, and all life forms, depend. Specifically, the impacts of large urban populations and the intensive agriculture that they depend on have severely impacted the supply of fresh water (Carpenter & Biggs, 2010). In the future we will have to use water resources much more carefully and efficiently while managing the major portions of our water catchments more effectively.

It has become increasingly clear that harmful changes in the earth's climate have been accelerating considerably faster than the scientific community anticipated. While there are good reasons that scientific assessments tend to be conservative (Brysse, Oreskes, O'Reilly, & Oppenheimer, 2013), astonishment about the extent and rapidity of change are becoming the norm in global warming circles (Carey, 2012; National Wildlife Federation, 2013; National Climate Assessment and Development Advisory Committee, 2013; Lyall, 2013). The level of urgency is thus chronically understated, and our response continues to be inadequate.

Efforts to limit emissions from fossil-fuel combustion alone are incapable of stabilizing levels of carbon dioxide in the atmosphere.

In theory, balancing the sources and sinks of atmospheric carbon dioxide can address, at least in part, human-induced climate change. However, natural sinks are decreasing because agricultural land, grasslands, coral reefs, and rain forests are being degraded at an increasing rate. To balance carbon dioxide flows it is believed to be necessary both to restore and protect these environments in addition to making drastic cuts in fossil-fuel use (Goreau, 1992). Efforts to limit emissions from fossil-fuel combustion alone are incapable of stabilizing levels of carbon dioxide in the atmosphere.

Twenty-five years ago it seemed straightforward that reducing emissions would lower the amount of carbon in the atmosphere and substituting non-carbon energy sources would be both technologically feasible and culturally acceptable. Accordingly, almost all efforts to combat global warming have only been directed at controlling sources, and primarily only fossil fuel sources at that, ignoring the extensive quantities of carbon emitted from degraded soils. As a result the emissions reductions strategy has, to date, been a decisive failure. Despite the fact that after almost three decades of attempts on the part of governments,

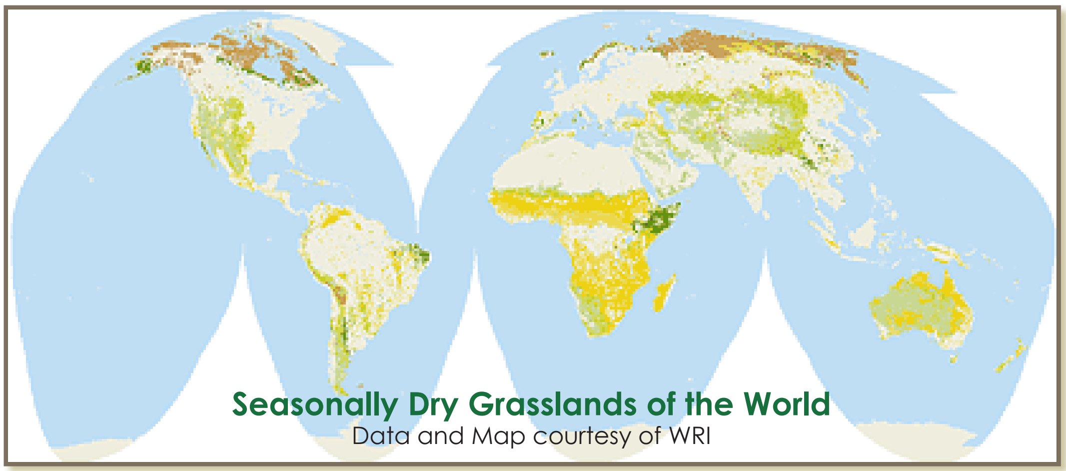
DECADE	TOTAL INCREASE	ANNUAL RATE OF INCREASE
2003–2012	20.74 ppm	2.07 ppm/year
1993–2002	16.73 ppm	1.67 ppm/year
1983–1992	15.24 ppm	1.52 ppm/year
1973–1982	13.68 ppm	1.37 ppm/year

Figure 1 Atmospheric CO2 is accelerating upward from decade to decade. For the past ten years, the average annual rate of increase is 2.07 parts per million (ppm). This rate of increase is more than double the increase in the 1960s, and 100x that of natural glaciation cycles. Data courtesy of co2now.org and retrieved at http://co2now.org/current-co2/co2-trend/

non-governmental organizations, the scientific community, and citizens worldwide, the total atmospheric carbon burden has increased by approximately 42 parts per million (ppm) to our current level of 393 ppm (NOAA, 2013), and the rate of increase is accelerating (International Energy Agency, 2012). See figure 1.

Since it has become increasingly apparent that emissions reductions will not take place in a reasonable timeframe, there have been alternative proposals for reducing the concentration of atmospheric greenhouse gases by actively removing them from the atmosphere. The advantages of such undertakings include the opportunity to bypass the impossibly slow international agreement processes and the possibility of succeeding in reversing global warming in spite of persistent ongoing emissions. Unfortunately, most of these proposals rely on high-tech geo-engineering schemes, which are largely untested for effectiveness, may be fraught with unintended consequences, and are potentially very expensive in both direct economic and indirect environmental and social costs.

Since it is well known that terrestrial environments are important global carbon sinks and the size of this sink depends on the grasslands of the world, the most feasible and cost-effective approach to carbon sequestration is in restoring the massive sink in degraded grassland soils.



- *Non-woody grasslands*
- *Closed shrublands*
- *Woody savannas*
- *Non-grassland area*
- *Open shrublands*
- *Savannas*
- *Tundra*

It is well known that terrestrial environments are important global carbon sinks (Prentice, et al., 2001; Schimel, et al., 2001) and the size of this sink depends on the grasslands of the world (Pacala et al., 2001) therefore, the most feasible and cost-effective approach to carbon sequestration is in restoring the massive sink in degraded grassland soils.

Grasslands are home to 1 billion people with pastoral traditions (from the Masai to the herder, to the gaucho to the cowboy). Not only do their traditions affect the management of grasslands, their management of this complexity affects all of humanity.

Globally, grasslands comprise 40% of the global land surface area, excluding Greenland and Antarctica and have been degrading primarily through cultivation and improperly managed livestock practices (Millennium Ecosystem Assessment, 2005).

Properly managed livestock used to restore and maintain the health of this Zimbabwean grassland.

At least one billion people depend on grasslands for their livelihoods mostly through livestock production for food and fiber (Ragab & Prudhomme, 2002). Therefore, there are huge economic and social costs associated with the degradation of grasslands apart from the diminished role they are able to play in sequestering carbon.

Although many attempts have been made to adopt technical solutions to reverse degradation, most involve large amounts of capital and expensive technology involving energy inputs from unsustainable sources, can be culturally inappropriate, and have not been successful in creating large-scale, sustained improvements to the landscape.

An adaptive and flexible framework to restore ecosystem function in Colorado, United States

The good news is that numerous instances from around the world attest to the fact that degraded grasslands can be restored by properly managing livestock to benefit biodiversity and ecosystem health (Hodgson & Illius, 1996; Savory and Butterfield, 1999; Tainton et al., 1999). To achieve restoration and sustainable use worldwide requires low-input technology, as well as management procedures that are adaptable and use a suitable flexible framework to restore ecosystem function. This is being accomplished in many locations around the world by changing the way livestock managers make decisions to achieve ecological restoration and enhance their livelihoods and quality of life.

Photo by Matilda Essig

A direct consequence of restoring ecological function to these ecosystems is that carbon sequestration is significantly enhanced. By renewing the relationship of grazing animals to grasslands, long-term storage of carbon in soils will remove carbon from the atmosphere and add vast quantities of carbon to soil organic matter (Judy, 2011; Lovell 2011; Itzkan, 2012).

Unfortunately, at this point in time most climate advocates are resistant—often fiercely so—to the use of grazing animals, particularly livestock, to sequester carbon

By renewing the relationship of grazing animals to grasslands through Holistic Planned Grazing, long-term storage of carbon in soils will remove carbon from the atmosphere and add vast quantities of carbon to soil organic matter.

in soils. There are several reasons for this: misunder-standing of the capacity of soils to sequester carbon; ignorance of the extent of carbon emissions from soil loss through human activity over millennia (Ruddiman, 2003); the lack of understanding of the extent and potential of grasslands to be a carbon sink; current perception about the damage inflicted by livestock (for example, Steinfeld, et al., 2006); and the almost exclusive attention to emissions reductions.

The purpose of this white paper is to challenge the exclusive focus on emissions reductions and shed light on a process of atmospheric carbon capture and storage that has developed in the natural world over millions of years, has minimal possibility for unintended consequences, and has myriad benefits for the health of lands worldwide as well as their dependent life forms which include humans.

THE LIFE OF GRASSLANDS SOILS

To address why attention has not been adequately placed on the importance of soils and the role that grazing animals can play in building healthy soils, a brief discussion of how soils work is helpful.

In healthy soils carbon is stored in stable complex biomolecules, such as lignin and glomalin, which remove carbon from the atmosphere and store it in the soil for hundreds or even thousands of years.

When grazing animals eat perennial grasses, the root systems die back and become feed for communities of bacteria (Baskin, 2005), leaving porous passages and carbon-rich biomolecules which are aggregated into a sticky substance called humus (Pucheta, Bonamici, Cabido, and Diaz, 2004). The following season the root systems regrow along with the plants above ground, and the process will repeat itself, increasing soil porosity, water and, carbon content annually. Lignin, glomalin, and protein fragments from root dieback, along with humus created by bacterial action comprise the process of humification, which is part of the liquid carbon pathway (Jones, 2009a). Humus is critically important in water retention, balancing minerals, and adjusting pH and is why healthy soils are dark in color (like elemental carbon and is shown in the photo to the right), relatively low in density, and clump, not crumble, when handled.

Photo by Christine Jones showing the dark colored carbon sequestered around the roots of perennial grasses.

Soil organic carbon, which constitutes approximately 60% of soil organic matter, has beneficial effects on the chemical, physical, and biological functions of soil quality (Bardgett, 2005), and increases water-holding capacity and contributes to soil structural stability (Weber, 2011). Soil organic matter increases adsorption of nutrients, cations, and trace elements that are of importance to plant growth;

Left: Initially in this neighboring, paired site comparison in Australia, parent material, slope, aspect, rainfall, and farming enterprises, as well as soil carbon in both were originally the same. On the left, the 0–50cm soil profile is from a pasture in which groundcover has been actively managed (no-tilled cropped and holistically grazed) to enhance photosynthetic capacity. On the right, the 0–50cm soil profile is from a conventionally managed neighboring paddock (10 meters through the fence) that has been set-stocked and has a long history of phosphate application. While the carbon levels in the 0–10cm increment are very similar (this surface carbon results from the decomposition of organic matter (leaves, roots, manure, etc.) forming short-chain unstable "labile" carbon, the carbon below 30cm in the left hand profile has been sequestered via the liquid carbon pathway and rapidly incorporated into the humic (non-labile) soil fraction. Photo and Research: Christine Jones. Property: 'Winona', operated by Colin and Nick Seis.

prevents nutrient leaching; and is integral to the organic acids that make minerals available to plants. Organic matter also buffers soil from strong changes in soil pH (acidity). Consequently, it is widely accepted that the carbon content of soil is a major factor in overall soil health, plant production, and the health of water catchments as well as being a sink for atmospheric carbon to offset climate change (Charman and Murphy, 2000; Lal, 2008).

The extremely complex and symbiotic functions of these life forms cannot be replaced with synthetic chemistry, which, on the contrary, eventually lead to massive soil erosion and wholesale loss of stored carbon to the atmosphere. Conventional agriculture that uses synthetic fertilizers and pesticides, as well as improperly managed livestock destroy essential soil biota and lead to widespread soil degradation (Neely and Fynn, 2011). It is well known that such soils become "addicted" to artificial inputs, requiring larger and larger "fixes" over time while yielding diminishing outputs (Khan, Mulvaney, Ellsworth & Boast, 2007).

In terms of livestock production, the modern industrial approach to animal husbandry has so distorted society's idea of what it means to raise cattle and other grazing animals that many do not understand how essential they are in creating a healthy grassland when properly managed. For when grazers are constantly on the move in response to predators, the search for a varied diet, and avoiding their own wastes, they aerate, fertilize, and restore the soils (Frank, McNaughton, Tracy, 1998). This is the opposite of what occurs under mainstream grassland management where cattle, protected from predators and permitted to graze randomly over wide areas without regard for the condition of the grasses, overgraze, compact and destroy soils.

On Gabe Brown's 4,000-acre farm in North Dakota, through no-till cropping combined with Holistic Planned Grazing, the following results have been documented:

- 278% increase in organic matter.
- 16-fold increase in water infiltration: 1/2"/hour to 8"/hour.
- 13.6" of rain in 22 hours with zero erosion.
- 127-bushel corn yield compared to just under 100-bushel county average in addition to the beef produced.

On pastures that were seeded with perennial grasses organic matter went from under 2% to 7.3% with grazing alone.

A typical, modern way to raise beef in feedlots.

On the right, a mixed herd of goats and cattle managed to mimic the wildebeest and zebra on the left. Photo of domestic herd courtesy of CJ Hadley/Range Magazine

Holistic Planned Grazing renews the proper relationship of grazing animals to grasslands by insuring that the animals are in the right place, at the right time, with the right behavior, for the right reasons. Through each cycle every component of this complex system nourishes all the others, resulting in rich soils which, storing vast quantities of water and carbon, remain moist even during periods of drought, raise the water table to restore and maintain perennial streams and ponds, and create habitats for richly diverse microbial, plant, insect, and animal life.

HOLISTIC PLANNED GRAZING: MAKING GRASSLANDS WHOLE AGAIN

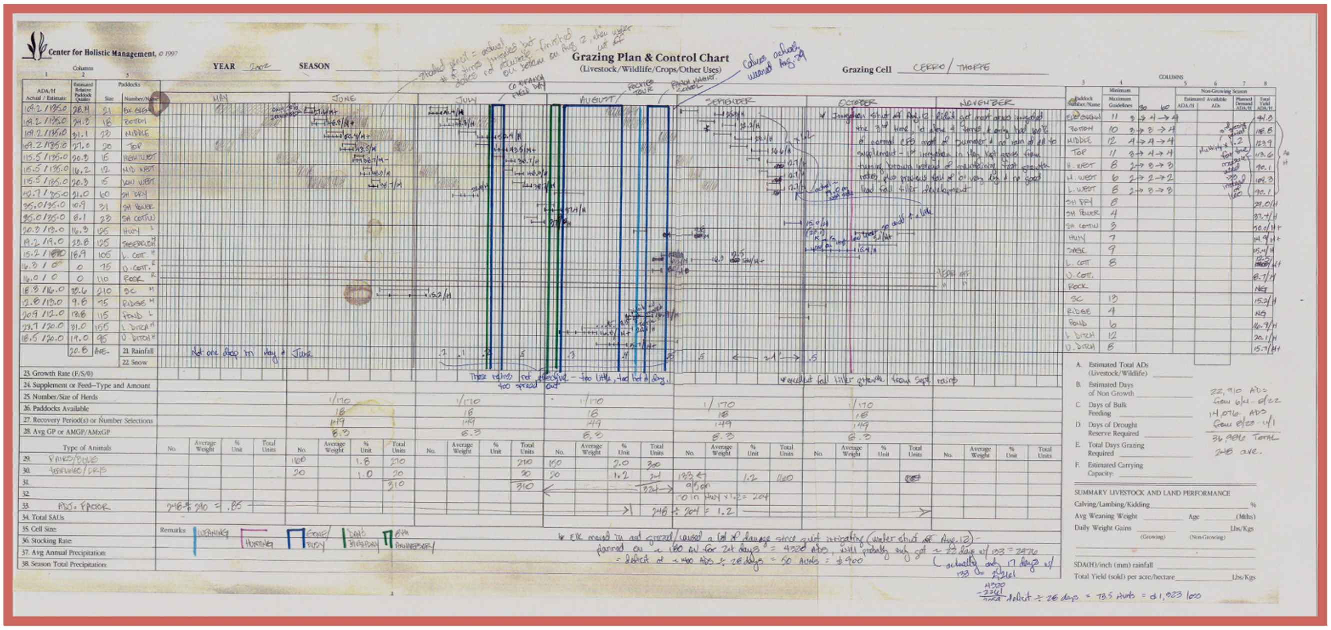
Although many grasslands have been badly degraded, it is possible to properly manage livestock to reverse this trend. Well-managed grasslands have a very important role to play globally as providers of livelihoods, water catchments, and biodiverse habitat for a multitude of plants and animals (Milchunas & Lauenroth, 1993; Savory and Butterfield, 1999). In addition, they hold a large reserve of soil carbon which, when released under degradation, contributes to carbon dioxide emissions. However, under restorative management degraded grassland can enhance soil carbon sequestration (Derner et al., 2006; Allard et al., 2007; Soussana et al., 2010; Teague et al., 2011).

Allan Savory, Founder of Holistic Management

An innovative biologist in Zimbabwe named Allan Savory pioneered Holistic Management and its planning process, Holistic Planned Grazing. Thanks to Savory and others, for decades we have been learning how to restore grasslands by mimicking nature. In fact, the synergistic nature of eco-restoration is a prominent theme throughout Holistic Management. The process involves re-establishing the evolutionary relationships between grazing animals and their habitats. Successful conservation-minded grassland managers practicing Holistic Management enhance the health of the ecosystem upon which we depend, as well as improve their profitability and quality of life. This is done while simultaneously providing ecosystem services desired by society through building soil, water, and plant resources (Walters, 1986; Holling & Meffe, 1996; Stinner et al., 1997; Reed et al., 1999; Savory and Butterfield, 1999; Barnes et al., 2008; Teague et al., 2009).

To accomplish this, Holistic Management practitioners combine scientific principles and local knowledge to manage animals to influence the following four ecosystem processes:

1. Efficient sequestration of solar energy by plants, otherwise known as energy flow;
2. Interception and retention of precipitation in the soil, thereby creating an effective water cycle;
3. Optimal cycling of nutrients through an effective mineral cycle; and
4. Promotion of high ecosystem biodiversity with more complex mixtures and combinations of desirable plant species, otherwise known as community dynamics.



Holistic Grazing Plan and Control Chart

A typical illustration of the essential process of soil restoration through Holistic Management, beginning with mostly bare, dry ground and using any of a wide variety of animals as grazers, from cattle to goats to sheep to bison is as follows:

Holistic Grazing and Land Planning in Zimbabwe

South Africa with very erratic 200mm of rain. The land on the left has been holistically managed since the 1970s. The land on the right is an example of what results with over-rest.

First and foremost, a Holistic Grazing Plan is created in order to properly manage livestock. This plan anticipates when and how long the animals will be in any given area.

When implementing the Holistic Grazing Plan, animals are herded in tight groups, confined to relatively small paddocks (either by permanent fence, but more likely now with temporary electric fence and/or herding), having intense but brief impact (several hours to a few days) on the land. They eat the grasses, forbs, and shrubs available—the more diverse the better (Provenza, 2007).

The plants that are eaten are carefully observed for signs of overgrazing. That is, land managers focus on adjusting the amount of time in any given paddock based on continuous observation and plan modification. This feedback loop is an essential element of Holistic Management, that is, managers plan (and assume that the original plan may be wrong), monitor the plan, control (that is, make adjustments as necessary), replan, and again monitor and control (Savory and Butterfield, 1999).

During their first impact on degraded soils, the properly managed animals break the soil cap with their hooves, fertilize it with urine and dung rich in gut bacteria, and trample plant matter into the soil surface, including dead grasses which when left standing and oxidizing interfere with new growth. This disturbance stimulates biotic activity by facilitating circulation of oxygen, carbon dioxide and other gases, by providing nutrients, by allowing penetration of water (Weber, 2011), and by providing land cover to minimize or eliminate bare ground. Most important, in fact, is to cover the ground with dung and trampled grass which holds water in the soil, thereby raising the effectiveness of the rainfall. Grassland biodiversity flourishes as the area of bare soil diminishes. Thus ruminants are organs as essential to living grasslands as stomachs and hearts are to mammals.

In response to the suffering grassland habitats worldwide (Suttie, Reynolds & Batello, 2005) conventional wisdom prescribes "rest" for deteriorated grasslands—that is, removal of animals for years or decades. However, such rest does not work to restore grasslands in semi-arid or arid climates (what in Holistic Management terms are called "brittle" environments), which comprise 75% of all grasslands on the planet. Despite clear evidence that over-rest is destructive, not restorative, the application of over-rest remains firmly entrenched in the dominant paradigm (Beschta, et al., 2012).

It should be noted that Holistic Planned Grazing acknowledges the tool of rest as essential in brittle environments when used for plant recovery. The purpose of such rest is, after proper grazing and animal impact, bitten plants and their roots are allowed to recover and regrow. The rest period may be anywhere from 30 days to 2 years depending on factors such as the climate, time of year, animal density, precipitation, and many other factors (Savory & Butterfield, 1999). This period of rest is an essential part of the holistic planning process, which always includes the return of intense short-term grazing and animal impact pressure after the recovery period, mimicking the way nature cycles animal impact in wild herds. Being eaten above the growth point is necessary for health in many grasses, which, in evolutionary terms, may be why the most nutritious grasses taste so good to the animals. Holistic Planned Grazing's rest period is measured in a time span based on how long it takes the plants to recover, not several years or decades, over which time the deleterious effects of over-rest become increasingly apparent.

By using the tools of grazing and animal impact and paying attention to adequate plant recovery, in a period of as few as three years, many long-disabled processes come back to life. For example, insects such as dung beetles return. They retrieve ruminant excreta and store it more than 18 inches beneath the surface creating new soil and storing carbon in the process (Richardson & Richardson, 2000). Worms and small mammals such as moles and prairie dogs churn the soil, while deep-rooted perennial grasses regrow and create channels for water and gases. Mycorrhizal fungi, with literally thousands of miles of hyphae in a small patch, transport nutrients which they have the unique ability to obtain minerals from soil and exchange them for carbohydrates from photosynthetic plants. The fungi synthesize a stable glycoprotein, glomalin that holds 4 to 20 times its weight in water. Microorganisms join the elaborate fray, and in the process create complex carbon molecules that store carbon deep in the soils for a long period of time (Jones, 2009a). These are the healthy soils that Holistic Managers throughout the world strive to recreate, capturing carbon, providing food, re-establishing balanced hydrological and nutrient cycles, and imparting beauty to the land (see next page).

Dying plant and deteriorating soil due to over-rest.

During a multi-year, worst-recorded drought in history, cattle return to a recovered sagebrush-steppe pasture in Wyoming, United States that had been rested for 570 days to give plants adequate time to recover. In "typical" years with adequate precipitation (10. in./yr.), plants would tend to recover in about 180 days.

Dung beetles building soil because sheep were brought back to this once over-rested grassland in Patagonia, Chile.

These pictures are of neighboring properties in Mexico, Arizona, and Zimbabwe, respectively. They are taken on the same day, have similar soils, and the same precipitation. The pictures on the right are examples of properly managing livestock through Holistic Management to restore grasslands. On the left we see examples of improperly managed livestock as well as exclusion from grazing.

CALCULATING SOIL CARBON SEQUESTRATION POTENTIAL

When looking at the potential for soils to sequester carbon the discussion and research has focused almost solely on soils that already exist. These are geological in origin and accumulate slowly, over thousands of years. Very little attention has been placed on biological soil that can be created quite quickly through Holistic Planned Grazing (Jones, 2002). This has lead to a dramatic underestimation of soil organic carbon storage capacity in assessing sequestration potential with respect to global warming. Furthermore, there is the predominant assumption that soils have a carbon sequestration capacity that is limited. Both estimates, however, effectively remove new soil creation from the equation and thereby underestimate soil sequestration capacity by a yet unknown but potentially significant magnitude. Thus soil creation of biological origin, which can be rapid in grasslands, remains unaccounted for. As Christine Jones notes:

The rates of soil formation provided in the scientific literature usually refer to the weathering of parent material and the differentiation of soil profiles. These are extremely slow processes, sometimes taking thousands of years...Topsoil formation is a separate process to rock weathering and can occur quite rapidly under appropriate conditions. In fact, soil building occurs naturally in most terrestrial habitats unless reversed by inappropriate human activities, or prevented by lack of disturbance [i.e., grazing]... If the land management is appropriate, evidence of new topsoil formation can be seen within 12 months, with quite dramatic effects often observed within three years (Jones, 2002, p.3).

Since most of mainstream soil and rangeland science has yet to seriously investigate complex biodiversity and the biological creation of soils, at this point in time we must rely mostly on the experience of practicing farmers and ranchers and some pioneering researchers both in and out of academia to estimate soil carbon sequestration potential.

For calculation purposes a discussion of soil characteristics is in order. First of all, mineral soil has a higher bulk density (is more compact) than biologically created soil, and is far more easily eroded. Soil loss figures usually assume an average bulk density (weight per unit volume) of around 1.4 g/cm^3 (Edwards & Zierholz, 2000). If one millimeter of soil is eroded (about the thickness of a 5-cent coin) that represents about 14 tons/hectare (t/ha) soil loss. When new topsoil is forming, it will have better structure and will contain more air and more pore spaces than degraded soil, so the bulk density will be less. That is, a given volume of new topsoil will weigh less than an equal volume of mineral soil. The bulk density of healthy topsoil may be as low as 0.5 g/cm^3. In practical terms, a one-millimeter increase in the height of new soil would equate to the formation of around 5–10 t/ha of organically enriched topsoil (Jones, 2002, p. 5). Therefore, for our estimations we will make a reasonable assumption of bulk soil density in healthy biological soils of 1g/cm^3.

Neighboring, paired site comparison in Australia. The soil on the left is from a pasture in which groundcover has been actively managed (no-tilled cropped and holistically grazed) to enhance photosynthetic capacity. On the right, the soil is from a conventionally managed farm (10 meters through the fence) that has been set-stocked and has a long history of phosphate application. Photo courtesy of Christine Jones.

Properly managed livestock building soil organic matter in Patagonia, Chile, being moved as planned to ensure adequate plant recovery.

Holistically managed bison in South Dakota, United States, restoring their ancestral soils.

Since there are 1 x 10^8 cm^2/ha, to a depth of 1 cm, we have 1 x 10^8 g of soil per hectare, or 100 t/ha. Soil organic matter will vary according to soil characteristics. For example, Jones (personal communications, 2013) says that it ranges from 50–62%. Lal, (2001) states that soil organic matter is generally estimated at 58% of soil organic carbon, which we will use in our examples. If we reasonably calculate that 1% of total topsoil weight is composed of soil organic matter (Troeh, 2005), then the weight of soil organic matter will be:

Total Weight of Soil	x	% Soil Organic Matter (SOM)	x	% Soil Organic Carbon (SOC)	=	Weight of SOC per cm of soil depth
100 t/ha	x	.01 (1%)	x	0.58 (58%)	=	0.58 tC/ha/cm

To calculate the quantity of carbon captured from the atmosphere and stored in organic molecules in the soil in terms equivalent to those used by climate advocates, the equivalent formula is expressed as follows:

Soil organic matter as a percent of total soil weight	1 %	x
Soil organic carbon – 58% of soil organic matter	58%	x
Soil density in g/cm^3	1	x
Depth in cm.	30	x
Billions of hectares	1	=
Total weight of carbon in soil in gigatons per billion hectares		17.4 Gt C

That is, at a standard soil measurement depth of 30 cm, we would have a total soil carbon weight of 17.4 Gt carbon captured per billion hectares. Or, in terms of atmospheric carbon dioxide, 8.7 ppm. This does not account for the greater and more stable carbon accumulation in the soils, up to 4 meters deep, which are created by the interactions of plant roots, mycorrhizal fungi, bacteria, small mammals, and insects as the health of the land returns.

Just to explore the potential possibilities, here is an example of applying the formula above to a soil which, at 100 tons per hectare we increase the soil organic matter by 2% of which 58% is soil organic carbon: a density of 1 g/cm3, 40 cm deep over 1 billion hectares of grasslands would yield 46.4 gigatons of carbon.

If we were to capture 1 ton of carbon per acre per year on the roughly 5 billion hectares of grasslands worldwide, we would remove 12 Gt of C from the atmosphere per year, that is, 6 ppm annually. If gross soil sequestration were approximately 6 ppm/year, after subtracting current annual carbon emissions of 2.5 ppm/year net sequestration would be 3.5 ppm per year.

Holistically managed grassfed beef at Two Dot Ranch, Montana, United States.

In principle this returns us to pre-industrial atmospheric CO2 levels in less than 40 years. How realistic these numbers are is unknown, since the bases for them have yet to be tested. Nor does it yet take into account how to address potential pulses of carbon from melting permafrost and seabed sinks. However, it is apparent that beyond the current limited conventional perspective on soil sequestration of carbon the potential may indeed be promising. The absolute validity of these numbers is not completely known, since the bases for them have yet to be fully vetted. However, it is apparent that beyond the current limited conventional perspective on soil sequestration of carbon the potential is extremely promising while providing no negative consequences, but instead many opportunities.

CONCLUSION

Holistic planned grazing in the foreground. Loss of soil organic matter due to lack of ground cover and conventional management in the distance. Photo by David Marsh, Australia.

There are several conventional assumptions in different mainstream disciplines that are obstacles to re-establishing the evolutionary grassland-grazer relationship for long-term sequestration of carbon in soils and restoring atmospheric carbon dioxide to pre-industrial levels. Each of these disciplines—climate science and advocacy, rangeland science, and soil science—contributes its own prevailing assumptions.

The following erroneously prevailing assumptions are barriers to restoring climate at the scale and pace necessary:

- Grazing animals chronically overgraze rangelands and destroy soils which must be "rested" to be restored;
- Climate action should be focused on reducing emissions;
- Soils are a limited carbon sink, and new biologically generated soils are not part of the equation; and
- Soil sequestration of carbon is only significant in the first 30 cm, and soil carbon cycles through the atmosphere in 25 years or less.

Collectively these assumptions create a mechanistic view of how the world works and should be seriously questioned. These views interfere with a necessary paradigm shift. On the other hand, if the necessary paradigm shift occurs it will allow us to act more effectively on planetary eco-restoration, affecting such fundamental biogeodynamics as carbon and water cycles, not the least of which is the reversal of an extremely destructive anthropogenic atmospheric carbon burden.

In order to realize the potential hope that the grasslands of the world provide for us, we need to make the following shifts in perspective that underlie Holistic Management:

- Nature functions as complex, interactive wholes, and humans need to define and work within their given, localized holistic contexts.
- Nature is self-organizing, and when all the elements of biodiversity are in place ecosystem health is the norm, not the exception. There have been significant changes in geophysical and biological contexts over the ages, and these are exceptions that have altered the conditions affecting life many times throughout the earth's history.

Photo of stream in Wyoming, United States, taken moments apart standing on a bridge. Left: Upstream Land - properly managed using Holistic Management (150% increase in livestock numbers); Downstream Land - managed conventionally.

Nonetheless functional, resilient states of ecosystem health have been the prevalent condition under which living creatures have evolved and thrived.

- Healthy soils are complex collections of interdependent life forms, and as a synergistic system soil activity may become seriously impaired when any of its elements are compromised or destroyed, as currently occurs worldwide with chemical agriculture, mismanagement of grazing animals, and over-rest.
- Effective eco-restoration, of which Holistic Planned Grazing is an essential component, can restore grasslands and geophysical cycles and stabilize carbon in the atmosphere to mitigate the adverse and lethal effects of global warming.

Since the advent of agriculture, humanity has been moving carbon in the wrong direction—out of the soils and into the atmosphere. We plow and have a tendency to mismanage livestock leaving land bare for much of the year, exposing soil life and humus to sunlight, desiccation, and oxidation. On bare ground, photosynthetic energy necessary for humification is not harvested. We make matters worse by using fertilizers, thereby seriously inhibiting the flow of energy to fungi that make stable, carbon-sequestering molecules and stimulating growth in certain bacterial populations destructive to soil fungi. Unnecessary use of fire also exposes bare ground, destroys organic soil matter, and emits carbon into the atmosphere. And of course, we emit massive amounts of carbon from burning fossil fuels. These kinds of decisions may have seemed right at the time, but now we know that they are leading us to a soil and climate catastrophe.

Today we are in the early stages of understanding the extent to which soils can sequester atmospheric carbon. It seems clear, however, that improper management of livestock and soil models have led us to underestimate significantly the potential for reversing climate change by restoring soils. As a result, few see that restoring the evolutionary relationship between grazing animals and their grassland habitat is an essential part of the equation to restoring the climate. Furthermore, there are so many ecological, social and economic benefits that accrue from proper grassland management that, notwithstanding uncertainty with respect to ultimate carbon storage capacity, we are well advised to pursue such eco-restoration with all due dispatch.

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