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Working Paper

Implementing the Texas Coastal Exchange

Jim Blackburn, J.D., Professor in the Practice of Environmental Law, Department of Civil and Environmental Engineering, Rice University; Co-director, Severe Storm Prediction, Education and Evacuation from Disaster (SSPEED) Center; Faculty Scholar, Baker Institute

Megan Parks, SSPEED Center, Rice University

Henk Mooiweer, SSPEED Center, Rice University

Sam Zapp, SSPEED Center, Rice University

Andrew Keat, SSPEED Center, Rice University

Elizabeth Winston Jones, SSPEED Center, Rice University

The SSPEED Center at Rice University has been working for some time on a non-structural flood damage risk reduction concept that is centered on creating new economic opportunities for the owners of land lying below the 20-foot elevation line in the Houston-Galveston region. This land is subject to inundation by hurricane surge flooding, and most of it is currently in agricultural use with very limited human infrastructure. In studying Hurricane Ike, the SSPEED Center team observed that millions of acres of ranchland were inundated and proved to be quite resilient. Little short-term and virtually no long-term damage resulted to ranch lands, in contrast to areas with dense infrastructure like housing and homes, which were inundated. Indeed, the saltwater wetlands and coastal prairies recovered to full ecological function and economic productivity after a period of time.

However, this region is also among the, most rapidly fragmenting regions in the country because of urbanization. One method to avoid future hurricane flood damages on the Texas Coast is to help keep these ranches in traditional land uses – uses that do not require dense human infrastructure and can therefore be inundated without incurring substantial damages. William J. Merrell, professor of Marine Sciences at Texas A&M Galveston and Father of the Ike Dike Proposal, agrees, stating in his research that one strategy for addressing vulnerability to storm surge is to limit or reduce human infrastructure. The approximately two-million-acre area originally targeted by SSPEED Center for non-structural flood damage mitigation is shown in the darker shading on Figure 1.

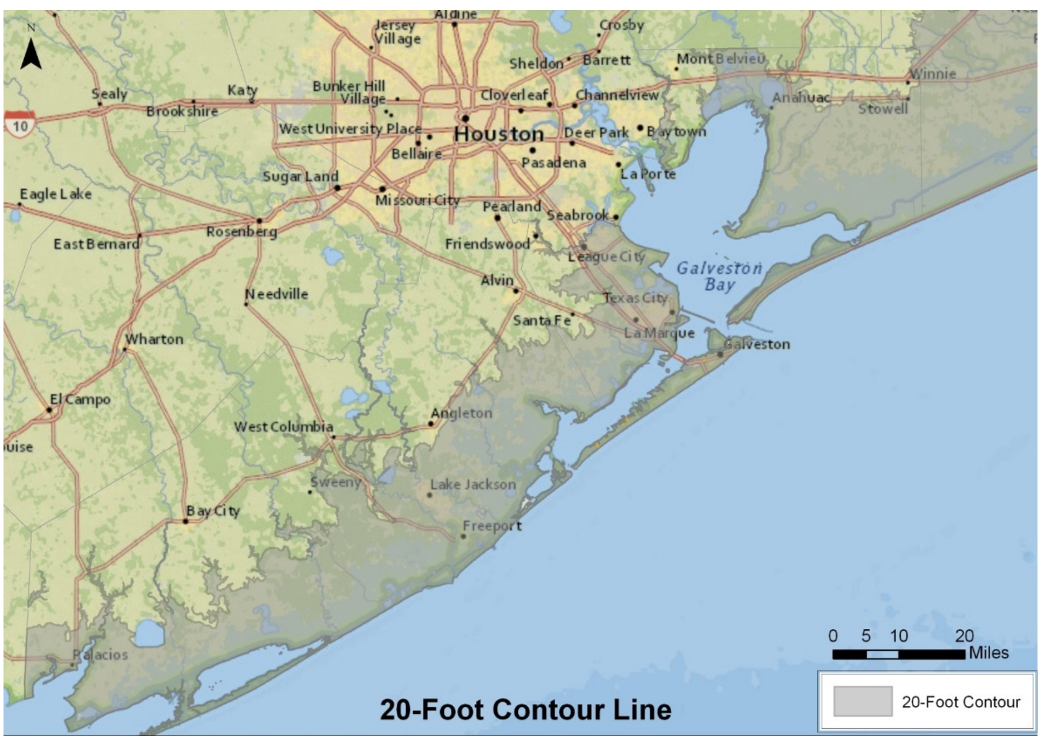


Figure 1. The area shown in gray lies below the 20 foot contour line, representing about 2 million acres in Chambers, Galveston, Brazoria and Matagorda Counties on the Texas Coast.

Recently, Hurricane Harvey dealt the City of Houston, the Houston-Galveston region and the Texas Coast a devastating blow. A similar, but less damaging, "Tax Day Flood" event was experienced in April 2016. How Houston and the region respond to this terrible historic flood event will be crucial for the region's future. Harvey's damage resulted mainly from torrential rains and resulting Bayou and drainage system flooding. Although the SSPEED center focused initially on hurricane surge, we realized we need to expand our attention to include the prevention of watershed induced flood damage.

In many areas of the United States, zoning or other land use controls might be proposed to keep natural, flood-prone areas from being developed. However, land use regulations are unpopular on the Texas Coast and are unlikely to be adopted even if Texas county governments had the authority to implement such regulations. For this reason, the SSPEED Center research looked to innovation and the market system to find a creative solution to protect these important natural areas.

In seeking a market-based solution, the research focused on identifying additional sources of income for landowners that could be generated from land uses that do not require much infrastructure and could survive inundation. This focus led us toward land management, cattle grazing and stewardship – concepts with the potential to generate new streams of revenue. Here, we focused on ecological services which are defined as the "goods" produced by natural ecosystems. Traditional ecological services familiar to landowners would include raising cattle on grasslands, leasing land for quail or deer hunting or selling timber produced by the land. Some of the less traditional ecological services include the sequestration of atmospheric carbon dioxide in soil and biomass, the reduction of flooding by absorption and storage of rainfall within the soil and wetland depressions, the enhancement of water supply as rainfall stored in the soil migrates, restoring and maintaining seeps and springs, and the enhancement of fish and wildlife values. With the development of an ecosystem services marketplace, economic and hazard resilience could be provided over large landscapes essentially by restoring and maintaining traditional landscapes, including native prairie, grazing lands and forests and wetlands.

The Texas Coastal Exchange (TCX)

In order to enable this eco-services marketplace, the SSPEED Center has proposed to develop an entity called the Texas Coastal Exchange. The Texas Coastal Exchange establishes a trading clearinghouse where willing buyers and sellers could come together and enter into transactions involving the sale of ecological services. Research undertaken over the last three years has revealed the existence of several ecological services trading systems, some resulting from regulatory requirements and some voluntary. However, most of these existing systems either were inapplicable to the Texas coast or had terms that would be unacceptable to Texas landowners. Additionally, many of these systems were overly complex. In response to these findings, the Texas Coastal Exchange was developed to be landowner friendly and relatively simple to join and implement.

Further, in evaluating the feasibility of such an ecosystem transaction economy, it became apparent to the research team that a long-term existential challenge faces the agricultural community. Rural communities have been losing population and economic stability for decades, and some would suggest that our heritage of Texas ranching – if not farming – is in jeopardy. If a system could be developed to bring economic vitality to this important community, then social benefits as well as economic benefits could be realized.

In pursuit of a non-structural flood damage reduction strategy, the SSPEED Center is proposing to develop and implement the Texas Coastal Exchange (TCX) system to restore and conserve ecology, land and soil at a scale that matters by supporting land owners and providing additional income from an eco-services market, when they improve their land and protect and restore ecology. The TCX has the potential to significantly enhance both social and economic resilience while providing carbon and water storage. This system could become extremely important in the effort to address climate change by making vulnerable coastal areas, as well as other at-risk areas, more resilient.

The basic concept of the Texas Coastal Exchange is straightforward. Landowners who are either currently or potentially providing ecological services will enroll in the Texas Coastal Exchange by initiating ecosystem service "measurement", such as soil carbon, or water infiltration, on their property, a step that we have labeled "planting the flag". That property would then be described and registered on an official registry as intending to participate in ecological service transactions under the standards established by the Texas Coastal Exchange. No cash transactions would occur until a period of time had passed after the initial testing. At a time in the future, testing would again be undertaken, and the relative increase in ecological service value would be determined. At that time, the landowner could decide to enter into a transaction with a willing buyer if the price were right. In subsequent years, additional testing would be required prior to further sales.

Carbon Dioxide

One of the key markets the SSPEED Center team has identified as a target is the purchase of carbon dioxide storage rights. Carbon dioxide [CO_2] is a naturally occurring substance that is emitted by natural decomposition as well as by fossil fuel combustion. In nature, there is a so-called carbon cycle. In this cycle, carbon dioxide in the atmosphere is transformed by photosynthesis in plants into carbohydrates that they need to grow and produce. Some of this carbon becomes biomass such as trees and plants and other carbon goes into the root system as root mass or to microbes that feed upon sugars released by the root system. Over time, some of this carbon biomass is decomposed and transformed back into carbon dioxide gas that moves back into the atmosphere, thereby completing the carbon cycle.

Today, our carbon cycle is out of balance. We are emitting more carbon dioxide from fossil fuel combustion, cement production and land degradation, than is being removed from the atmosphere by photosynthesis and by other natural sinks such as the oceans. This carbon dioxide is building up over time in our atmosphere and is contributing to the so-called "greenhouse effect." Carbon dioxide has been labeled as a greenhouse gas along with other molecules that have a similar effect on the atmosphere, such as methane. These greenhouse gases have been identified as the primary agents causing climate change, the effects of which include an increase in atmospheric temperatures, increased severe storms and droughts and other similar changes, all of which can have severe impacts on humans and human settlement patterns. For this reason, there is increasing pressure on emitters of carbon dioxide to take steps to reduce carbon dioxide emissions.

Carbon Neutrality

There are three ways to reduce carbon dioxide emissions to become "carbon neutral". An emitter can (1) avoid, (2) minimize and/or (3) capture or remove emissions. To avoid emissions, users can pursue sources of energy that involve no direct emissions such as solar or wind. To minimize emissions, users can become more efficient through better insulation and design, through low emission vehicles or by purchasing energy star appliances, for example. But for those carbon emissions that remain after avoidance and minimization, the only path remaining to carbon neutrality is by removing and storing carbon dioxide emissions. Although several engineering solutions have been developed, implementation is slow due to high cost and lack of scaling options. It appears that the only proven technology that is scalable and inexpensive is soil or biological storage. When agricultural or grazing lands are managed differently, plants, insects and soil microbes begin to thrive, initiating natural processes by which vast amounts of carbon dioxide are captured by photosynthesis and pumped into the soil. If you are a hydrocarbon supplier or refiner, soil carbon storage is likely the only affordable and scalable way to neutralize the impact of your operations and the emissions from your customers' use of your products on the Earth's climate.

As the issue of climate change becomes ever more urgent, pressure is mounting upon the oil and gas community to undertake action to reduce carbon dioxide emissions and limit their impact on atmospheric CO_2 levels. Last week, the maritime industry identified that it would become carbon neutral, representing 3% of global carbon emissions. Volvo recently announced it would manufacture only electric and hybrid vehicles in the future. Monsanto has announced plans to become carbon neutral, as have several cities and the province of British Columbia. Every major corporation in the world has calculated its carbon footprint. They all just have not decided what, if anything, to do.

SSPEED Center research has estimated that the carbon footprint from the operation of a 150,000-barrel per day refinery, as well as the customer carbon footprint from use of the refinery's products, could be sequestered by storing about 25 to 30 million tons of carbon dioxide per year. At 4-5 tons of CO_2 per acre per year (an ambitious goal), this footprint could be sequestered on about 5 to 6 million acres of grazing land. Soil carbon storage might offer novel business opportunities. For example, a car manufacturer might purchase in advance the carbon footprint of an internal combustion engine vehicle, allowing their customer to drive a carbon neutral car at a relatively low cost. We anticipate that consumers will demand these options in the future.

Putting a Carbon Flag in the ground

Landowners who restore native ecosystems or manage their grasslands in a regenerative way, are already storing carbon in their land. But until a carbon "basepoint" is established by testing, it is impossible to know how much carbon dioxide is being removed from the atmosphere by a particular piece of property. Once that basepoint is set, then a second test can be conducted after a few years to determine the amount of carbon dioxide removed from the atmosphere and stored in the soil as soil carbon. The measured increase in carbon storage in the soil can then, after independent verification and validation, become a saleable commodity on the Texas Coastal Exchange. An illustration of this concept is set out in Figure 2.

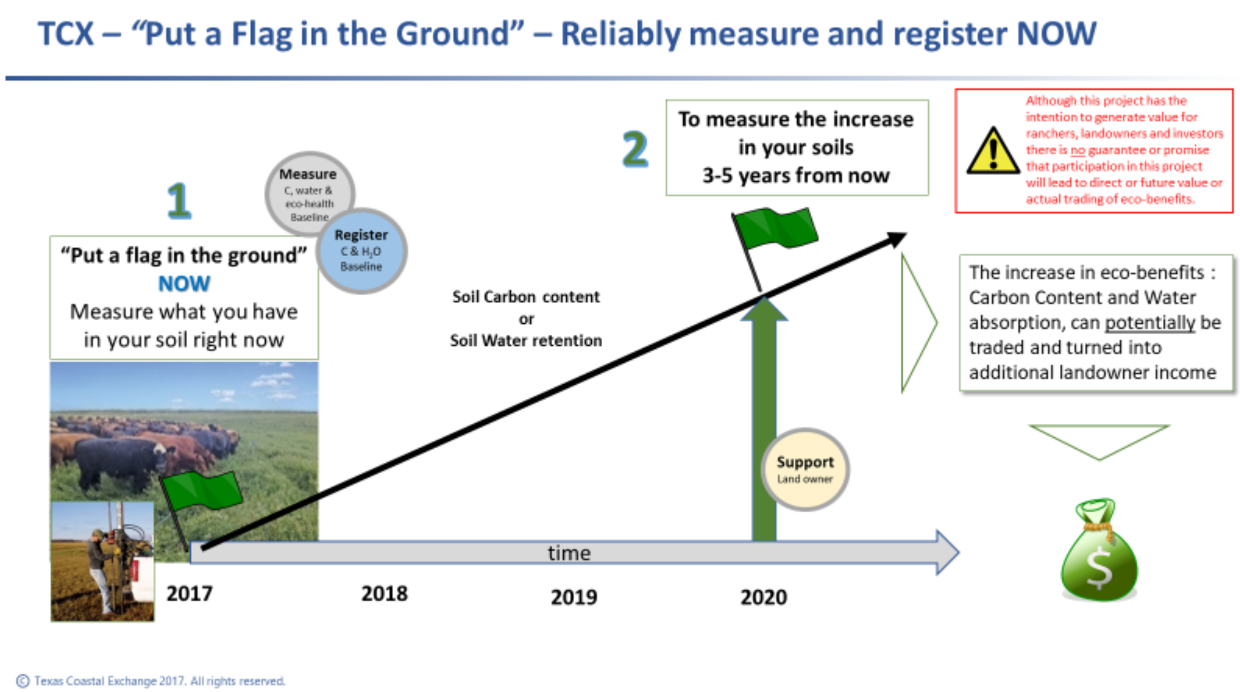


Figure 2. Illustration of the basic concept of testing to initiate ecosystem service measurement. Note that no carbon transactions can occur without basepoint and subsequent testing.

In the view of the project team, soil carbon dioxide sequestration is like growing potatoes. If you are a "carbon farmer", you undertake certain action, bear the fruits of that labor, and then sell it.

Currently, there is a modest voluntary market for the purchase of soil carbon dioxide storage capacity. However, as more and more corporations, institutions and individuals move toward carbon neutrality, the demand will likely increase. Calculations reviewed by the SSPEED Center team reveal that there is unlikely to be sufficient capacity in the soil or biomass to store all existing, much less future, carbon dioxide emissions each year.

For this reason, the modest carbon dioxide market of today is expected to become more robust and to vastly expand in the not-too-distant future. This is why the Texas Coastal Exchange will initially focus on carbon dioxide storage in the soil, but the exchange will also be used for flood abatement, water supply enhancement and more general ecological service value transactions.

Water resilience

When landowners manage their lands differently they not only store vast amounts of carbon in their soils, but they also create a wide range of other ecological benefits. One of those benefits is soil water storage. Initial data reviewed by SSPEED center demonstrates that the water retention of grasslands with healthy soils can be ten times higher than in degraded grasslands. During heavy rainfall events, soil health can mean the difference between severe flooding downstream within the watershed, or no flooding. Ecologically healthy soils with high water retention are more drought resistant and hence provide economic resilience to landowners. Proper land management in a watershed provides a low-cost way to prevent downstream flooding and can thus supplement or even altogether replace costly more traditional engineering solutions.

The Texas Coastal Exchange enables landowners to be paid for the flood prevention services they provide. Soil water retention benefits could potentially be quantified, verified, and traded on the exchange. As with carbon, TCX water storage trading methodologies will be based on scientifically robust measurement and independent verification and validation, to ensure the TCX only trades proven and measured benefits. Although this paper focuses primarily on soil carbon storage and trading, the TCX also intends to rapidly introduce the trading of other key eco-benefits, such as water retention.

The Texas Coastal Exchange Trading Standards

As discussed, one goal of the SSPEED Center in creating the Texas Coastal Exchange was to enhance the economic viability of the Texas Coastal agricultural community and maintain agricultural and ranching activities and culture. For this reason, the standards of the Texas Coastal Exchange have been tailored to support economic development as well as to achieve ecological and social goals. Initially, TCX has focused upon carbon transactions although other transactions may be implemented as well. A typical carbon trading system is set out in Figure 3.

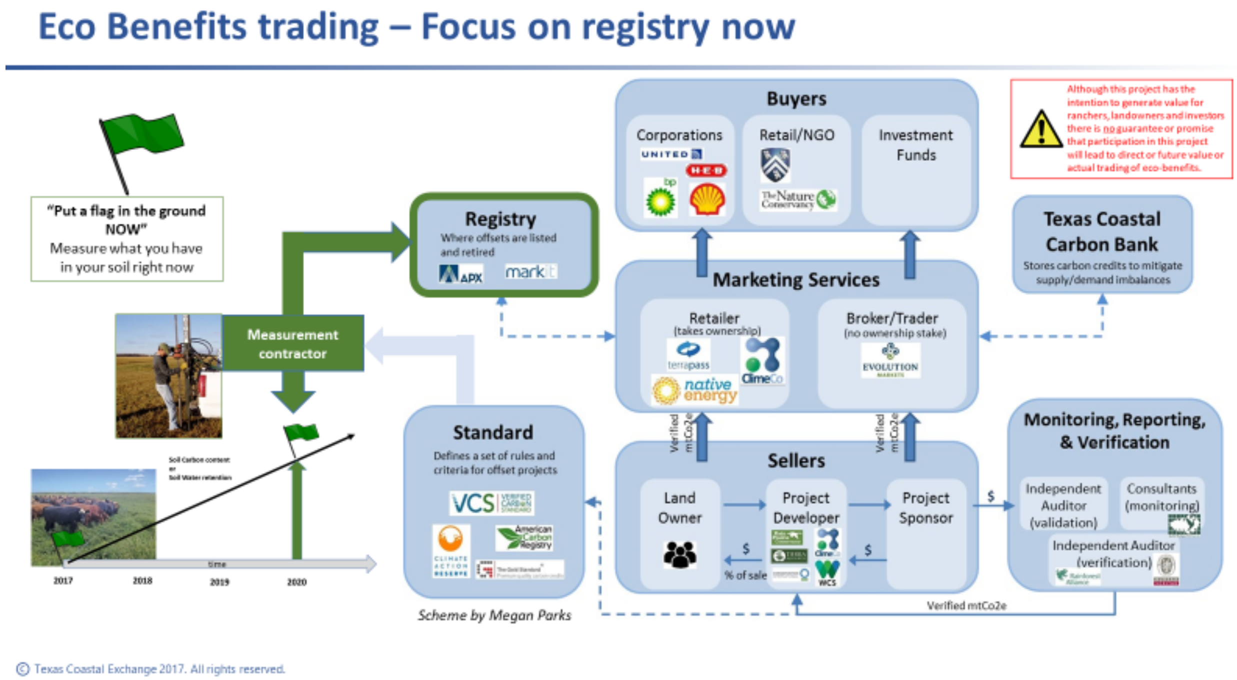


Figure 3. Diagram showing the various participants in carbon transactions. Both buyers and sellers must agree upon a standard and the standard must have a relationship with a registry.

As shown in Figure 3, there are several inter-related pieces in a typical carbon transaction. The system is bracketed by buyers and sellers. Often, there is a marketer between the buyer and seller, although that is not always the case. The standard setting organization is absolutely essential in that the rules and standards set by this organization define the requirements for participation under that standard. Both the buyer and seller must agree and be comfortable with a standard or else no transaction will occur. All commodities traded must be registered to obtain unique identification numbers to eliminate fraudulent sales. And there is a necessity for monitoring, verification and validation procedures to ensure rules and standards are being applied and that the transactional value and integrity is maintained.

The SSPEED Center research team has determined that some of the more prevalent carbon trading rules and practices are not well suited to the goals of the TCX system because they tend to significantly restrict landowner participation and therefore work against the goals and objectives of the TCX program, if not against a global goal of quick and efficient removal of carbon dioxide from the atmosphere. For this reason, the SSPEED Center team has determined that a separate set of trading rules and standards need to be developed that are different from the rules and standards practiced in existing exchanges. These rules and departures will be explained in the following paragraphs.

1. Legal Structure of the Texas Coastal Exchange

The overall structure of the Texas Coastal Exchange is shown in Figure 4. TCX is incorporated as Texas non-profit corporation at this time. The key objective is support landowners to migrate from conventionally managed lands to improved and restored lands that provide the portfolio of eco-benefits. The core of the TCX system is shown in the vertical rectangle that includes the TCX entity itself, the Buyers Club and the Sellers Club. The function and scope of TCX entity is in development, though is expected to serve as the clearinghouse through which Buyers and Sellers Clubs transactions occur. The Buyers Club includes corporations and possibly individuals. It will provide capital to enable the launch and rapid scaling of the system, including funding various landowner development programs. In exchange, the Buyers club members will receive several benefits, which might include first right of refusal on future carbon credit sales. The Sellers Club includes primarily landowners such as ranchers, as well as not-for-profits and co-ops comprised of smaller landowners. The Sellers Club will commit to sell carbon credits under the TCX and offer first right of refusal to the Buyers Club. Funding from the Buyers Club will be used to provide Sellers Club members with soil testing, expertise on land management concepts and adaptive development of carbon testing protocols. These three functions will form the core of the Texas Coastal Exchange.

The actual trading will be accomplished according to the process set out on the right side of Figure 4. Essentially, TCX will be the trade enabler between buyers and sellers, with both buyers and sellers contracting through the TCX. All carbon traded through the TCX will be registered to identify specific saleable tranches of the soil carbon “crop” measured by qualified firms. All transactions will be pursuant to standards developed by the TCX with the assistance of a supervisory board. On the left side of the diagram, the relationship between the TCX and the AMP grazing research project led by Peter Byck of Arizona State University is shown. This project aims to scientifically determine the impacts of Adaptive Multi Paddock grazing on a wide portfolio of eco-benefits. Similarly, we are developing relationships with numerous land management advisors, including the US Department of Agriculture Natural Resource Conservation Service (NRCS) and farm and ranch organizations.

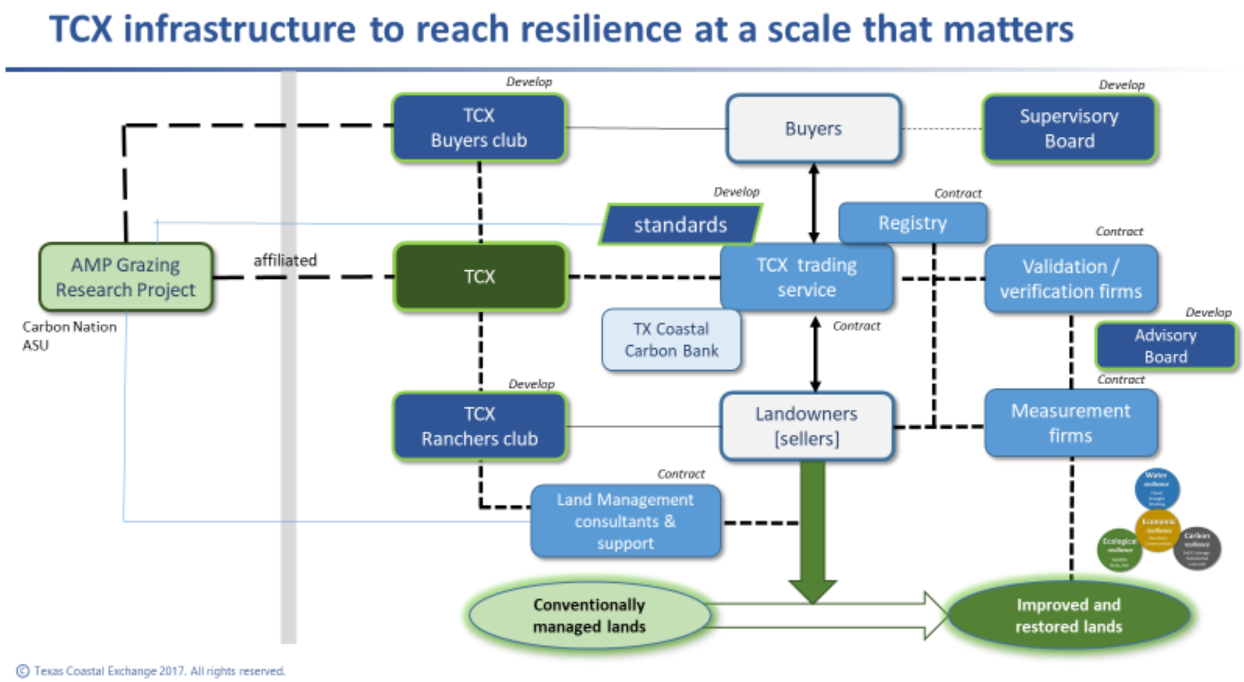


Figure 4. Flow chart showing connections of various activities within the TCX framework

A summary of the rules and standards follows. At this point in time, the long-term relationship of TCX with Rice University has not been determined, although some type of continuing connection with Rice would be beneficial to TCX if not Rice.

2. Property Rights

Carbon dioxide storage as soil carbon by a landowner is treated as a property rights concept under the TCX. If you can prove and document that you have increased the amount of carbon in your soil, then you may sell that "stored carbon dioxide" (measured as carbon in the soil) through the Texas Coastal Exchange. The landowner also may undertake any other activities on the property which are not inconsistent with carbon storage, including cattle ranching, hunting, eco-tourism, water supply enhancement, flood reduction and fish and wildlife enhancement. The landowner can realize income from multiple ecosystem services on the same property and is encouraged to do so.

3. Rules and Standards

The Texas Coastal Exchange will allow the sale of atmospheric carbon dioxide removal and other ecosystem services to the extent that the existence of the service can be reliably measured and documented. In the case of carbon dioxide, proof is required that the tons of carbon per acre of soil have increased. Buying and selling of flood reduction for riverine systems will be based on soil infiltration capacity or possibly using vegetation (e.g., native prairie) as a proxy variable. Buying and selling of fish and wildlife production will be based upon vegetation or ecosystem type. Further research is necessary to fully explore buying and selling of water supply enhancement capability, but it likely will be based upon vegetation or ecosystem type, both commonly used in existing voluntary and regulatory markets as proxy variables.

No seller may sell carbon storage through the TCX unless a basepoint is measured and the property is enrolled on a registry approved by TCX. All transactions will be by commodity sales contracts with a contractual commitment from the seller that the sold commodity will remain in place for a minimum number of years, which will likely be determined as either 10 or 20 years from the date of the sale. The sales of subsequent carbon sequestration from the same piece of land (e.g., the yield from years 4 to 6, 7 to 9, etc) will carry the same requirement for a sequestration time commitment, leading to a continually expanding commitment horizon.

4. Registration

One or more existing registries will be identified by TCX for use in qualifying projects for TCX-sanctioned transactions. In order to register a property, a landowner must provide a legal description of the tract and must have undertaken carbon or other appropriate testing prior to registration. The purpose of the registration is to develop a unique identification method for each transaction to prevent selling the same carbon or other services to multiple buyers. Tradeable units of a particular ecosystem service, for example tons of carbon stored, will not be listed on the TCX registry until after they have been validated and verified by an independent third party verification body.

5. Monitoring and Measurement

Measurement is a core requirement of the Texas Coastal Exchange. If a landowner wishes to sell carbon dioxide through the TCX, then the amount of carbon in the soil must be determined in a scientifically and statistically sound manner. In order to do this, independent measurement experts, approved by TCX, will evaluate, in consultation with the landowners the terrain, soil type and vegetation types. Depending on the nature and size of the property, TCX standards require a minimum number of one-meter deep soil core samples to be tested per soil horizon per soil type, with each soil horizon being separately tested. Calculations will then be made and added together across soil types on the property. Subsequent monitoring replicates the initial measurement protocol in approximately the same location. TCX will attempt to secure either grant or loan funding for farmers and ranchers who wish to enroll but lack sufficient capital to do so, and will work with the ranching community to develop a dependable pool of testing contractors and valid, reliable and workable statistical protocols.

6. Independent Validation and Verification

Independent validation and verification is a core component of the TCX, with the purpose of assuring that all carbon or other ecosystem services sold are real and verifiable. Before any ecosystem service credits are executed, a qualified, independent third-party verification firm will review the landowner's documentation and the associated monitoring reports, and issue a statement verifying the amount of carbon claimed to have been stored. This is a critical step that guards against fraud, ensures the credibility of the exchange, and provides buyers with a high degree of confidence that the carbon stored is real and has been quantified correctly. Based on SSPEED research to date, it is expected that most major buyers of credits, as well as the major registry operators, will require independent validation and verification in order to partner with the TCX.

7. Transaction Commodity Contracts

All transactions will be by commodity contract. The terms and conditions of the model commodity contract have yet to be determined but will include the required registry information for the seller's offering, the tons to be transacted, and the sequestration longevity time of the contract. The standard contract will identify the type of insurance required in case of default to ensure that the purchaser receives carbon dioxide storage for the agreed amount of time. Discussions and research are ongoing about methods for ensuring the time commitment for carbon remaining in the ground. All contracts are enforceable under standard commodity contract law.

8. Buyers Club

At the current time, the market for carbon is relatively calm, with larger bulk buyers being hesitant to get too far ahead of their competitors. On the other hand, it appears from preliminary research that overall global soil and biomass sequestration is limited and less – even with improved land management practices -- than current, much less projected, emissions. Based on this assessment, it is reasonable to conclude that when the market develops, supply will be less than demand. Assuming that access to storage capacity is necessary for market penetration if not operation, the ability to access carbon storage in the future will be quite important, if not essential, to hydrocarbon-centered businesses. For this reason, TCX has created a special preferred category for potential buyers whereby they receive the right of first refusal to offerings through the Texas Coastal Exchange as long as they offer prevailing market price.

In order to become a member of the buyer's club, a substantial membership fee must be paid to the TCX. These initial funds will be used to support landowners to measure the basepoint as well as to provide land management consultancy support to landowners to rapidly enhance their land and soils. This approach allows the TCX to reach a scale that matters to the Buyers. If collective demand among the

Buyers Club members is greater than supply, then a bidding process will be undertaken among the potential buyers to allocate the tendered tons on a pro rata basis. Based on initial feedback from potential members, we are seriously considering limiting initial membership in the Buyer's Club to offer sufficient competitive advantage and elements of limited exclusivity to early Buyers Club members. In this manner, a competitive advantage could exist for early commitments based on their help in developing the process and system.

9. Sellers Club

In addition to the Buyers Club, the TCX will include a Sellers club for the landowners that join the TCX program. TCX will assist members of the Sellers Club in obtaining the funding and technical support they may need to participate in the exchange. For example, landowners could receive funding and technical assistance to establish their soil carbon basepoint, obtain timely and efficient registration and implement land management techniques to enhance carbon storage. The TCX will create a Sellers club member network where land management best practices and pragmatic support is exchanged between member landowners. Ultimately, the Sellers Club will become a conduit by which carbon credits are presented for sale through the Texas Coastal Exchange.

10. Management to Enhance Ecosystem Service Value

One of the key concepts of the Texas Coastal Exchange is that various land management approaches exist that can enhance the ecosystem service potential of a landowner's property. In particular, actions such as adaptive multi-paddock (AMP) grazing and natural ecosystem restoration appear, based upon the literature and anecdotal evidence, to increase the mass of carbon stored in the soil and enhance other ecological services as well. TCX will develop a portfolio of tools that support the network of landowners in the Sellers club to deploy management practices that increase ecosystem service value and thereby help the landowner realize greater income. TCX will collaborate with several land management consultancy organizations to provide hands-on support to landowners. In the early stages, TCX aims to offer consulting grants to interested landowners in order to optimize carbon dioxide removal and storage.

11. Compliance with Other Standards and Protocols

The TCX standards are different from other existing regulatory or voluntary carbon trading systems. This difference derives from the goals of TCX as well as the basic concept of TCX relative to carbon. The TCX views carbon dioxide and its removal and storage as a commodity – as a product. We are developing an exchange that pays a landowner for removing carbon dioxide from the atmosphere. If you remove it and store it you can sell it. Due to this approach, certain traditional concepts regarding additionality are largely absent from the TCX standard.

This approach was adopted because many of the existing additionality requirements do not work for Texas landowners. Further, they often do not make sense in light of TCX goals of optimizing carbon dioxide removal, generating maximum cash flow to keep landowners on their land and providing multiple ecological, economic and social benefits. There are two key requirements. First, the property to be entered into the TCX program must be registered and tested according to TCX standards, for carbon in the soil. Second, the landowner must prove that more carbon is in the ground at the time of sale than when the basepoint was first measured, and that they are offering the increased amount for sale.

Various existing exchanges have significant qualification criteria that we have considered and rejected. For example, in the TCX a landowner may sell carbon credits even if the landowner makes more money off of other commodities such as cattle or perhaps no till agriculture. It should be noted that in case of ranching the methane and carbon dioxide emissions associated with other uses must be netted out. TCX will allow credits to be transacted from regions where all landowners are exhibiting the same or similar management practices. We are depending upon private initiative and competition, and if one management technique is superior to all others, then it is likely to be adopted widely by other land owners in the region. The activities of neighboring land owners will not impact any given seller's ability to sell on the exchange. TCX will allow basepoint measurement and subsequent sale for ongoing land management practices if the landowner can document an increase in carbon in the soil over time. Our belief is that the contractual commitment at time of sale for leaving the carbon in the ground is a sufficient changed condition to warrant the exchange of credits.

The TCX is not trying to force one type of land management over another. That is the election of the landowner. However, the landowner will likely have more carbon to sell if they use certain management concepts and abandon others.

12. Stacking

Similarly, TCX is allowing and in fact encouraging "stacking" of benefits. The goal of the TCX is to increase economic, ecologic and social resilience. To this end, multiple ecological service commodities resulting from the same land management practice can be sold. In this manner, a carbon farmer could sell flood storage and water supply enhancement, while also running cattle and leasing the land for hunting. None of these transactions involve the same commodity although they result from the same land management practice. This is not double counting. This is good economic practice that benefits environmental and social goals as well.

Conclusion

There are many issues to be addressed in the future by the Texas Coastal Exchange. Perhaps the most difficult and important of these is the approach to additionality and the variance of the TCX protocols from current carbon trading standards that derive primarily from the Clean Development Mechanism of the

Kyoto Protocol adopted in 1997. It will be the topic of a separate paper to set out a detailed analysis of the issues associated with the many varied steps in classic additionality protocols. However, a few closing points seem in order.

First, the potential of grasslands to remove carbon dioxide from the atmosphere is immense, yet there are few to no grassland projects registered through the existing voluntary carbon protocols at this time. From our analysis, it is clear that the qualification requirements for participation in the existing exchanges are a huge impediment to realizing this potential. Given that grassland sequestration is one of the few options available for actually removing carbon dioxide and storing carbon in the soil, we should be doing everything that we can as professionals and as a society to enable and enhance grassland storage. These qualification policies must be reexamined and reconsidered if this large carbon dioxide removal source is to be realized.

Second, the TCX approach offers long-term ecological, economic and social benefits beyond hurricane surge, rainwater storage and carbon dioxide removal. Under this system, the native prairie systems can and will be preserved and enhanced over time, seeps and springs will be restored, base flow on streams and rivers will be higher during droughts, and the peak flow will be reduced for severe flood events. Fish and wildlife will benefit. The rural areas of Texas and the United States stand to be revitalized through the many new economic opportunities presented by the emerging ecosystem services industry. The TCX will offer the oil and gas industry access to options that will enable them a bridge into the carbon neutral future, offering light at the end of the tunnel for the economy and social stability outlook for states highly reliant on oil and gas-related jobs and economics.

Third, the proposed TCX system is market driven, not based on regulation and is compatible with personal and institutional values in Texas and many other conservative states. We need carbon, ecological, economic, and social approaches that can work for all of the United States. If we can design and implement this system in Texas, then it can make a difference.

The goal of the Texas coastal exchange is to develop and implement a system to restore and conserve ecology, land and soil at a scale that matters, by supporting land owners and providing additional income from an eco-services market, when they improve their land and protect and restore ecology. Reaching scale fast but responsibly is essential. By supporting landowners, TCX aims to remove at least 100 million tons of carbon dioxide from the atmosphere each year by 2022. It is doable. We just have to do it.

Appendix A: Carbon Sequestration Potential of Coastal Texas Environments

The Texas Coastal Exchange has identified four ecosystems present on the Texas Gulf Coast with significant carbon sequestration and ecosystem service potential. These environments are oyster reefs, coastal marshes, prairies, and bottomland forests. Additionally, special attention has been given to one carbon sequestration technique, adaptive multi-paddock grazing, due to its ease of implementation and potential to rapidly add to the soil carbon stocks of prairies and rangelands.

Oyster Reefs

Relatively little work has gone into quantifying the carbon sequestration potential of oyster reefs to date, and much of the information we have comes from environments that differ significantly from the Texas coast. Although more research needs to be conducted in the Gulf coast, rough approximations can be obtained by looking at studies from other areas. One study conducted on oyster reefs in Australia measured annual sequestration of between 1.54 and 7.26 metric tons/acre/ year, with most reports on the lower end of that range. This is not an especially promising rate of storage given the high cost of building man-made reefs. A 2004 project on the Chesapeake Bay in Maryland built 86.5 acres of reef at a cost of $3 million. This yields a cost of around $17,000/ ton C/yr to sequester carbon, using a reasonable sequestration rate from the Australian study. By all indications, oyster reefs are not an economically viable way to sequester carbon on their own. Luckily, oyster reefs provide several other significant ecosystem services including increased fishery health, structural defense against hurricanes, and water filtration. Carbon sequestration can therefore potentially be a small but significant component of the stacked benefits that could make oyster reef construction and/or preservation economically viable.

Marshes

Coastal marshes may have the best carbon sequestration potential of all ecosystem types as they have high sequestration rates and cover a large area of around 5.5 million acres along the Texas coast. Sequestration rates for coastal wetlands and marshes have been estimated between about .25 and 4 tons C/ acre/ yr, with the high variability largely due to widely ranging environments, vegetation types, sedimentation rates, and testing methodologies (see figure below for different studies). Low lying estuarine marshes account for the upper end of the sequestration potential range due mostly to their high sedimentation rate and subsidence, which rapidly bury organic carbon. These estuarine marshes are abundant along the Texas coast. A reasonable conservative estimate for average sequestration rate comes from Engle (2011), a compilation of various wetland studies along the Gulf Coast. It includes both lowland and higher elevation marshes and arrives at an average rate of 2319 lbs C/acre/yr, or just over 1 ton C/acre/yr.

Wetland Carbon Sequestration

Study	Year	Location	Carbon Storage (tons C/acre)	Sequestration Rate (lbs./acre/yr.)	Notes
Engle	2011	Gulf of Mexico	114	2319	Meta-analysis of wetland studies conducted along the Gulf Coast
Chmura et al	2003	World-wide	174	508	Carbon Sequestration rates are global averages
Choi et al	2001	Florida (low marsh)	129	8465	Closest to open water
Choi et al	2001	Florida (middle marsh)	67	5307	
Choi et al	2001	Florida (high marsh)	58	2168	Farthest landward
Schmidt et al	2014	Georgia	31		Only measured the biomass of first 30 cm of soil
Loomis et al	2010	Georgia		357	Conservative estimate
AVERAGES FROM ALL STUDIES			96	3187	

Source: Blackburn, J., Hale, C., and Gori, A., 2014, Ecosystem Services of the Mid-Texas Coast.

Wetland conservation is crucial to protecting soil carbon stocks, and will arguably need to take precedent over restoration. The Texas Coast has lost 30% of its freshwater coastal wetlands in the last 40 years, not only preventing future sequestration, but also releasing stored CO_2 back into the atmosphere from biomass and sediment storage. On a larger scale scale, destruction of tidal marshes has been estimated to contribute as much as .24 billion tons CO_2/yr, or .0655 billion tons C/yr, to global emissions (figure below).

Table 1. Estimates of carbon released by land-use change in coastal ecosystems globally and associated economic impact.

	Inputs			Results	
Ecosystem	Global extent (Mha)	Current conversion rate (% yr^{-1})	Near-surface carbon susceptible (top meter sediment+biomass, Mg CO_2 ha^{-1})	Carbon emissions (Pg CO_2 yr^{-1})	Economic cost (Billion US$ yr^{-1})
Tidal Marsh	2.2–40 (5.1)	1.0–2.0 (1.5)	237–949 (593)	**0.02–0.24 (0.06)**	**0.64–9.7 (2.6)**
Mangroves	13.8–15.2 (14.5)	0.7–3.0 (1.9)	373–1492 (933)	**0.09–0.45 (0.24)**	**3.6–18.5 (9.8)**
Seagrass	17.7–60 (30)	0.4–2.6 (1.5)	131–522 (326)	**0.05–0.33 (0.15)**	**1.9–13.7 (6.1)**
Total	33.7–115.2 (48.9)			**0.15–1.02 (0.45)**	**6.1–41.9 (18.5)**

Source: Pendleton L, Donato DC, Murray BC, Crooks S, Jenkins WA, et al. (2012) Estimating Global ''Blue Carbon'' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. PLoS ONE 7(9): e43542. doi:10.1371/journal.pone.0043542

Prairies

Native praries, which once covered around 6.5 million acres of land in Texas, have now been reduced to less than 1% of their previous area. With a reasonable sequestration rate estimate on the order of about 0.5 tons C/acre/yr for prairies, roughly 3 millions tons of annual carbon storage have been lost. Prairies have high potential in the TCX program for three reasons. First, enough native prairie loss has already occurred that there are now huge areas of land that are suitable for restoration back to their native state. Second, prairies and grasslands store a larger percentage of organic carbon in the soil relative to above ground biomass than other ecosystems such as forests, assuring longer-term carbon storage. Finally, improved land management practices on prairie and grassland ecosystems have been shown to greatly improve carbon sequestration rates in many cases. The TCX can help stimulate the adoption of these practices, which in turn could increase average annual sequestration rates to much higher than their current estimates. One such improved management practice is discussed in the next section.

Carbon Sequestration Rates Summary Table

Study	Year	Location	Prairie Type	Reported seq. rate (g C/m²/y)	Seq. Rate (lbs. C/ac/y)	Notes
Suyker, Verma	2001	Oklahoma	tallgrass	268	2386	Monitoring conducted in 1996-1998
Dugas et al	1998	Texas	tallgrass	80	712	
Sim, Bradford	2001	Southern Plains	mixed-grass	70	623	Bowen ratio/energy balance used
Potter et al	1999	Texas	restored grassland	48	428	Based on comparisons to a pristine prairie and degraded agricultural soil
			AVERAGES FROM ALL STUDIES:	**117**	**1037**	

Source: Blackburn, J., Hale, C., and Gori, A., 2014, Ecosystem Services of the Mid-Texas Coast.

AMP Grazing

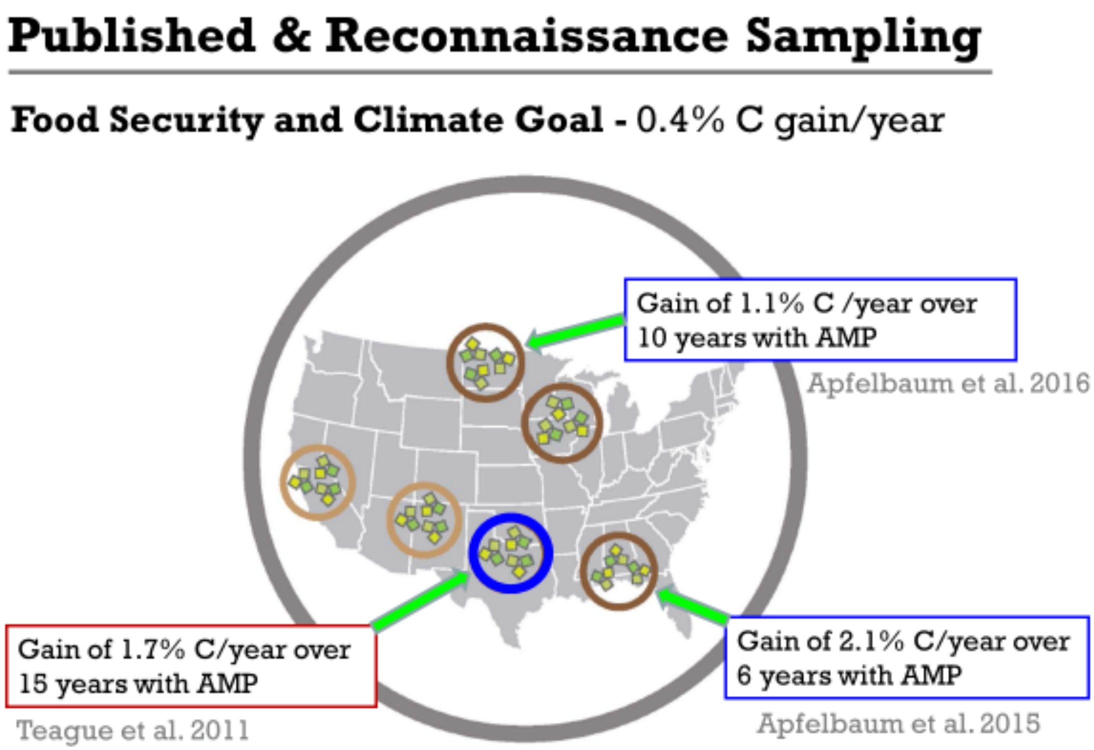
Adaptive multi-paddock (AMP) grazing is a flexible land management practice that uses multiple fenced paddocks for each livestock group to provide relatively short periods of grazing with moderate plant use and adequate time of recovery after grazing. This causes the grasses and vegetation to be grazed intensely, to a predetermined plant consumption for a short period of time, then given a long break to recover without cattle. This method emulates the way co-evolved grassland ungulates (e.g. bison, wildebeest, caribou, etc.) move across grasslands; usually quickly, and they may or may not return for a year or more (the recovery period) to the same area.

Several AMP grazing success stories are showcased in filmmaker Peter Byck's series *Soil Carbon Cowboys*, highlighting the practice's potential to increase land productivity and vastly improve soil carbon sequestration. In one case, a property's soil carbon content was over tripled. Adaptive Multi-Paddock (AMP) grazing, in relation to widespread continuous grazing practices, contributes to measurable differences in overall soil health, sequestration of atmospheric carbon in soils, greenhouse gas (GHG) respiration, animal health and well-being, rancher and farmer well-being and ranch and farm resilience, and delivery of ecosystem services on managed pastureland within the continental United States. [1]

Peer reviewed scientific study to back these anecdotal success stories has lagged behind, but is now beginning to come out. Recent studies by Texas A&M researcher

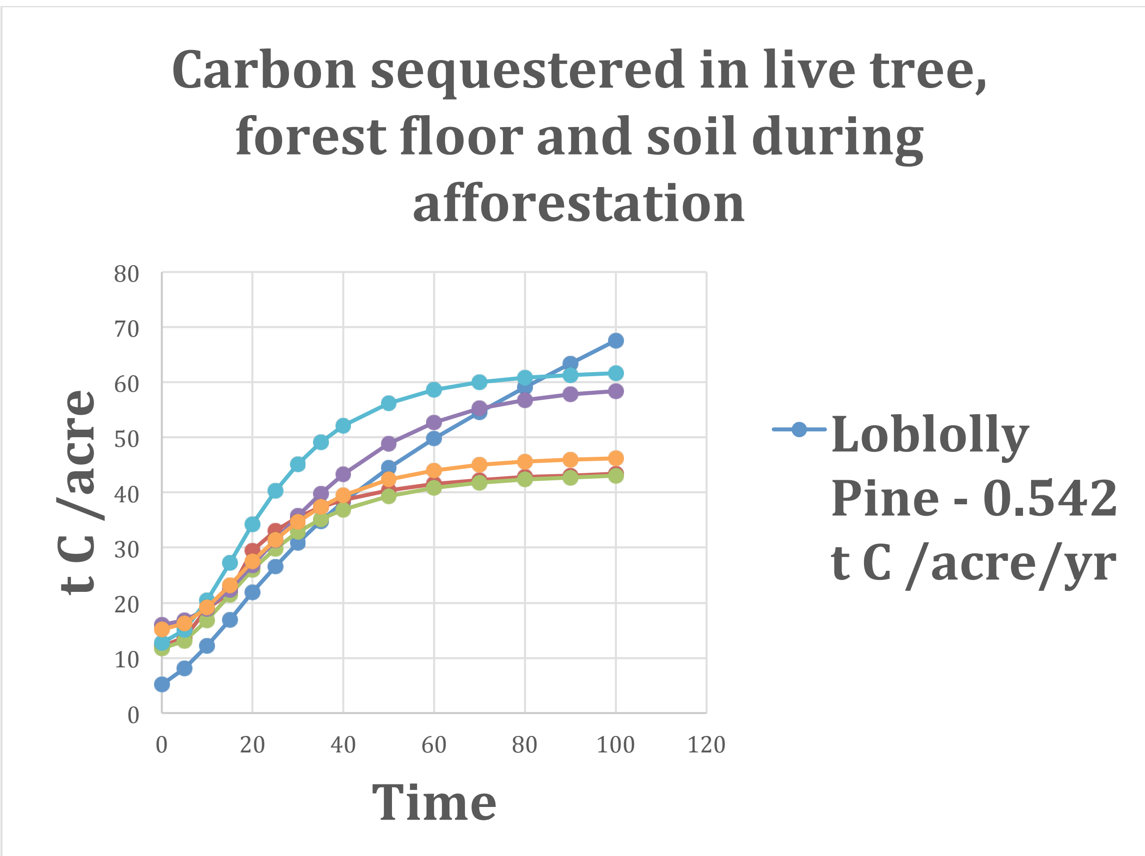
Richard Teague (Teague et al (2011), Teague et al (2013), and Teague & Barnes (2017)) have explained the phenomenon of scientific studies failure to capture the benefits of AMP grazing by pointing out that in an attempt to maintain objectivity, scientists have neglected the *adaptive* component of this management style in favor of rigid, easily repeatable procedures on a much smaller scale than a typical ranching operation. This fails to capture the practice's effects on biodiversity and evenness of grazing that occur at full scale, as well as the nuanced management decisions that well informed ranchers will make to suit individual tracts of land. The Teague papers argue that when selecting for studies done at full scale and managed by competent ranchers, the carbon sequestration potential and general ecosystem health of AMP grazed lands are significantly greater than those of conventionally managed lands.

An example of soil carbon storage data reported:



Timberlands and Forests

The potential to sequester CO2 in timber and forest lands is monumental. In Texas, there is 62.4 million acres of woodland and forestland and worldwide, there is 652.4 million acres. Many factors influence timberlands ability to sequester carbon such as the climate, age, and tree species with the biggest factor being the species. In general, younger and faster growing timberlands sequester more carbon. However, this does not mean that older forests are not sequestering carbon. Forests as old as 150 years have been shown to still be increasing their biomass and therefore capturing CO2. To give and example of some of the possible accumulation rates to be expected, according to the Texas A&M Forest Service reports Texas A&M Forest Service reports, the above ground live-carbon accumulation rates for the hardwood-bottomland and riparian forest types as 1.12 tons C/acre/year and 1.21 tons C/acre/year (Simpson 2013). Quantifying the amount of carbon locked up in above ground biomass may be one of the bigger challenges the TCX faces but we are working with many organizations, including NRCS, to find the most accurate and precise way to obtain measurements.



Data acquired from COLE carbon report

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Appendix B: TCX and International Standards

ISO Standards

The International Organization for Standardization (ISO) is the collective effort of over 160 national standards bodies that produce international standards. Some of these standards are related to greenhouse gas emissions reporting and quantification. All standards are non-governmental and voluntary, though regulatory organizations in some jurisdictions may choose to require compliance with ISO standards.

ISO standard 14001 is the broad umbrella under which all other environmental standards fall. It is very general and vague in its wording, and the most common standard for organizations to claim compliance with. Apart from ISO 14001, ISO 14064 and 14065 are the most relevant to the Texas Coastal Exchange (TCX), as they lay out a voluntary greenhouse gas project accounting standard and requirements for accrediting bodies to validate/verify carbon credits respectively.

ISO 14064 is a three-part document. Part 1 focuses on GHG emission and emission reduction quantification at the company/organization level, and is less relevant to the TCX's operation. Part 2 focuses on emissions reduction quantification, monitoring, and reporting at the project level, which is exactly what the TCX will need to engage in. Although 14064-2 doesn't lay out specific statistical models, it provides direction for how to fully describe a project; come up with a baseline; measure additionally; select and monitor GHG sinks, sources, and reservoirs; and correctly document projects. It largely references the CDM website (http://cdm.unfccc.int/methodologies/index.html) for specific quantitative methodologies.

Part 3 deals with the validation and verification process that regulators can take to ensure that greenhouse gas assertions (i.e. carbon sequestration claims) are real and accurate. That process includes making sure that the validator/verifier team is objective and free of conflicts of interests with clients or greenhouse gas programs (such as the TCX), competent in both the scientific/technical and legal sides of carbon sequestration projects, and subject to internal peer review. The level of risk associated with each project should also be qualified, and both the project and the validating/verifying body should agree upon the project's objectives, evaluation criteria, and scope at the beginning of the verification/validation process. Additionally, the idea of materiality, or the idea that the sum of multiple discrepancies between projected and actual project factors (carbon storage, timespan, etc.) could be large enough to cause the verifying body to alter their decision on a project, is introduced in this section and deemed necessary to include in the verification/validation process. Some organizations implement "materiality thresholds" to mitigate this problem, but much like additionality calculations, it is difficult to predict behavior and decision making under alternative scenarios. ISO 14064-3 also outlines how verifiers/validators will lay out a risk-based sampling plan, crosscheck greenhouse gas information, and ultimately assess whether or not a project reaches the validation or verification criteria.

The TCX will not act as a verifying/validating body as that would constitute a conflict of interest. However, understanding the process these independent regulators take could be instrumental to maximizing the success rate of sequestration project verification/validation.

ISO 14065 outlines the steps that validation/verification bodies need to take to ensure effective auditing of projects attempting to claim carbon credits. It follows in pretty much the same vein as ISO 14064-3, but with more specific competence requirements for verifiers/validators, records management, and verification appeals process among other provisions.

ISO and TCX

Compliance and consultation with ISO standards, while not required, offers several benefits. First, it provides a complete and well-organized set of accounting procedures to draw on while constructing a voluntary carbon registry like the TCX. It also lends credibility to a compliant trading system, thereby potentially attracting more sellers, and especially more buyers. Buyers operating in regulatory systems outside of Texas (i.e. international or California cap & trade) may find ISO compliance especially important because current or future regulation may mandate that their carbon credits be obtained through ISO compliant registries. The largest voluntary carbon registries in the U.S. (American Carbon Registry, Voluntary Carbon Standard, Gold Standard, and Chicago Climate Exchange) are based largely on ISO 14064.

Noncompliance with ISO standards may prevent the exchange of credits between registries and regulatory systems. For example, the California Cap-and-Trade Program currently only accepts credits from three outside registries, all of which are based on ISO standards. Both the California and Quebec cap-and-trade systems prescribe most closely to the Western Climate Initiative, which is heavily influenced by ISO 14064 and 14065. As a side note, the U.S.'s non-participation in the Kyoto Protocol already precludes TCX credits from entering the European Union Emissions Trading Scheme (EU ETS), the largest emissions trading system in the world.

At this stage in its development, the TCX is very likely compliant with both ISO 14001 and 14064-2. According to ISO 14001, organizations such as the TCX can make a "self-determination" or "self-declaration" of compliance with the standard, skipping the alternative of an expensive third party audit. Although not explicitly stated, the same presumably applies to ISO 14064.

The most significant barrier to the TCX being able to claim ISO 14064 compliance is the program's departure from traditional baseline-additionality requirements in favor of a "zero baseline". Measured increases in soil carbon levels between sampling events are credited to land owners. In the parlance of traditional carbon crediting systems, each sampling event resets a "zero baseline" where net carbon sequestration is taken to be zero in the absence of landowner action, and any soil carbon increases are issued as additional credits. After credits are issued for measured carbon stock increases, the baseline is readjusted to avoid double counting. This method isn't completely unprecedented in ISO methodology, as ISO 14064-2 states:

> "GHG programmes may adopt simplified approaches related to baseline estimation for some GHG removal enhancement projects, such as adopting a zero baseline for afforestation and reforestation on certain land use types, where prior land-use is assumed to be in carbon balance and hence sequestration is zero. This would then constitute an appropriate standardized/performance baseline scenario for such projects."

Zero standards may be used as long as the program justifies the rationale behind implementing them. One possible justification behind using a zero baseline for soil carbon sequestration could be that soil carbon stocks are relatively stable compared to above ground biomass. Another is that landowners have nothing stopping them from degrading their land by, for example, selling it into development. Net land use change is actually heading in this direction, as evidenced by wetland and native prairie loss figures, which can be found in Appendix A. Therefore, a zero baseline assuming no net sequestration in the absence of the TCX carbon credit market is actually sufficiently conservative because it does not project carbon negative land use change. Landowners in Texas, the Deep South, and the Midwest have very secure property rights, and the economic incentive of revenue from carbon credits may be the only way to keep land out of development.

The Clean Development Mechanism

The Clean Development Mechanism (CDM) was established (along with Joint Implementation (JI)) by the Kyoto Protocol as a way to standardize emissions reduction quantification in order to allow international credit exchanges. A project can become compliant by obtaining validation from an independent and CDM accredited designated operational entity (DOE). The project would then receive Certified Emissions Reduction (CER) credits, which are tradable with non-Annex-1 (i.e. developing) countries seeking compliance with the Kyoto Protocol. Credits generated by other schemes or registries aren't tender as CDM credits, however many registries generally accept CER credits (American Carbon Registry, Verified Carbon Standard).

CDM methodologies are much more specific than ISO standards, as they include equations and numerical models for estimating things such as changes in soil organic carbon stocks, as well as a stricter definition of additionality that includes barrier to implementation and common practice analyses. There is a methodology approval process where projects can get their own methodology approved provided that it adheres to the CDM definition of additionality and other requirements. Because the CDM is more stringent than ISO standards, it is possible to be ISO compliant without being CDM compliant.

The Texas Coastal Exchange (TCX) will be unable to achieve CDM compliance in its current structure due to specific requirements such as the additionality tests mentioned above. However, this is not necessarily a problem for three reasons. First, the TCX would not be able to trade its credits in the international CER trading scheme anyway because the CDM does not accept credits from any outside schemes or registries. Second, the TCX can claim ISO 14001 and 14064 compliance without becoming CDM compliant. If ISO compliance can be achieved, the registry will benefit from increased credibility for following an internationally recognized standard. Finally, the Paris Accord and other future climate agreement could soon make the CDM obsolete.

Policy Changes Going Forward

Just as the Kyoto Protocol established the CDM and JI, the Paris Accord has created the Sustainable Development Mechanism (SDM) which, although not yet in place, is expected to be an update on the CDM once it goes into effect after 2020. The SDM is still being developed, and there is a lot of uncertainty about what it will look like once its implemented. It is unclear whether the SDM will add on to the CDM, amend it, or replace it outright. The SDM is expected by many experts to be very similar to the CDM, but some are calling for large changes such as switching away from the idea of offsets and developing stricter rules for additionality. It remains unknown if methodologies will be drastically altered and if credits generated under the CDM will still be eligible for use once the SDM goes into effect. The U.S.'s recent decision to withdraw from the Paris Accord could affect how the SDM applies to credits generated within the U.S.

ISO standards will also change significantly in the near future. ISO 14080, titled *"Greenhouse gas management and related activities – Framework and principles for methodologies on climate actions"*, is expected to be released in 2018 and will provide an update to the ISO 14064-14069 standards. It will aim to adjust methodologies to fit the goals of the Paris Accord, 17 United Nations Sustainable Development Goals, and the 2030 Agenda for Sustainable Development. It promises to be a useful tool for "non-state actors, initiatives, industry associations and GHG programmes" such as the TCX.

Other Voluntary Carbon Standards

While CDM is considered a regulatory or jurisdictional standard, a multitude of other carbon standards have emerged to serve the voluntary market for carbon offsets. Chief among these voluntary standards are the Verified Carbon Standard (VCS) and the American Carbon Registry (ACR), which together represent approximately 55% of global voluntary carbon transactions. SSPEED Center has conducted extensive research into these two standards, as well as preliminary research into the Gold Standard and California's Climate Action Registry. While TCX incorporates many of the essential elements of these standards, the TCX approach differs from some of these voluntary standards in several key ways: baseline and additionality, measurement, and permanence.

Baseline and Additionality. With some exceptions, in order to qualify under the voluntary carbon standards studied, a project must pass a three-step additionality test. To certify carbon credits under these standards, a landowner would be required to demonstrate and document that his land management activities:

1) are not required by regulations, called a "regulatory surplus test"; and
2) are new in some way and/or different from the prevailing methods in that region, called a "common practice test"; and
3) would not have been implemented without the incentives provided by the generation of carbon credits due to either financial, technological, or cultural/social barriers, called a "barrier test".

In practice, this conventional additionality approach is costly, complicated, and time consuming, and disqualifies many of the Texas landowners who are leaders in implementing restorative practices on their land. For example, it requires the landowner to extensively document the baseline scenario, or the hypothetical business as usual scenario that would have occurred in absence of the project. Further, as regenerative practices become more widespread, it becomes difficult to pass the common practice test, and the ability to use carbon credits as an incentive for landowners diminishes.

As TCX's primary purpose is to incentivize regenerative and restorative land management practices, the TCX additionality approach seeks to include rather than exclude. For this reason, TCX will not employ traditional regulatory surplus, common practice, or barrier tests for additionality. Under TCX, the baseline scenario is wholly defined by the first set of soil carbon measurements at the start of the crediting period. TCX soil carbon baselines will be scientifically valid and measurement-based, as opposed to reliant on predictive modeling or implementation of a certain set of specified activities. This approach avoids costly and extensive justification of hypothetical scenarios and reduces the paperwork burden on landowners.

Measurement. Measurement is a core requirement of the Texas Coastal Exchange, to a greater degree than in other standards. If a landowner wishes to sell soil carbon credits through the TCX, then the amount of carbon in the soil must be determined in a statistically sound manner to the 95% confidence level on the basis of set of one-meter deep soil cores tested for each soil horizon and soil type, then composited across soil types on the property. Under existing voluntary carbon standards, measurement-based approaches to soil carbon represent only one of the allowable approaches; other valid methodologies may include activity based approaches, where credits could be claimed as long as certain land management activities were performed, with fewer requirements for deep core soil testing. However statistically valid, verified measurements will be a requirement under TCX. Approaches that rely solely on modeling and estimation will not be allowed.

Permanence. Some voluntary standards such as California's Climate Action Registry require land based sequestration projects to demonstrate that carbon will be sequestered for at least 100 years, in effect requiring permanent conservation easements. This approach does not work for the majority of Texas landowners. TCX will require landowners commit contractually to a minimum of 20 years continued sequestration past the point of sale. While more research is needed on enforcement mechanisms in the event of reversals, it is expected that TCX will utilize a pooled buffer pool approach or insurance products, similar to those employed VCS and ACR.

Similarities with existing exchanges. TCX will share many essential elements in common with established voluntary carbon standards. Similar to VCS and ACR, independent validation and verification is a core component of the TCX, with the purpose of assuring that all carbon or other ecosystem services sold are real and verifiable. Before any ecosystem services credit sales are executed, a qualified, independent third-party verification firm shall review the landowner's documentation and the associated monitoring reports, and issue a statement verifying the amount of carbon claimed to have been sequestered. This is a critical step that guards against fraud and ensures the credibility of the exchange. Further, TCX verified credits will be assigned unique identifiers, listed and tracked via a transparent registry system to ensure credits are sold to only one buyer.

TXC Course of Action

It will be essential for the TCX to keep current with incoming international greenhouse gas initiatives and amendments to the current system. The next five years will probably see a drastic overhaul of current regulation, and predicting what that may look like will be difficult. The TCX will provide justification that it complies with ISO 14064, as this standard is currently in effect, internationally recognized, and vaguely enough defined that compliance is a realistic possibility. When ISO 14080 is published, the TCX should look into claiming compliance with it as well. The TCX, however, shouldn't seek to achieve CDM/SDM compliance because doing so would require that it completely restructure its accounting process and incorporate strict additionality tests that would decrease landowner/carbon credit seller participation. CDM methodology could be a useful tool for the TCX to reference while creating its own quantification scheme, but it certainly doesn't need to be mimicked in its entirety.

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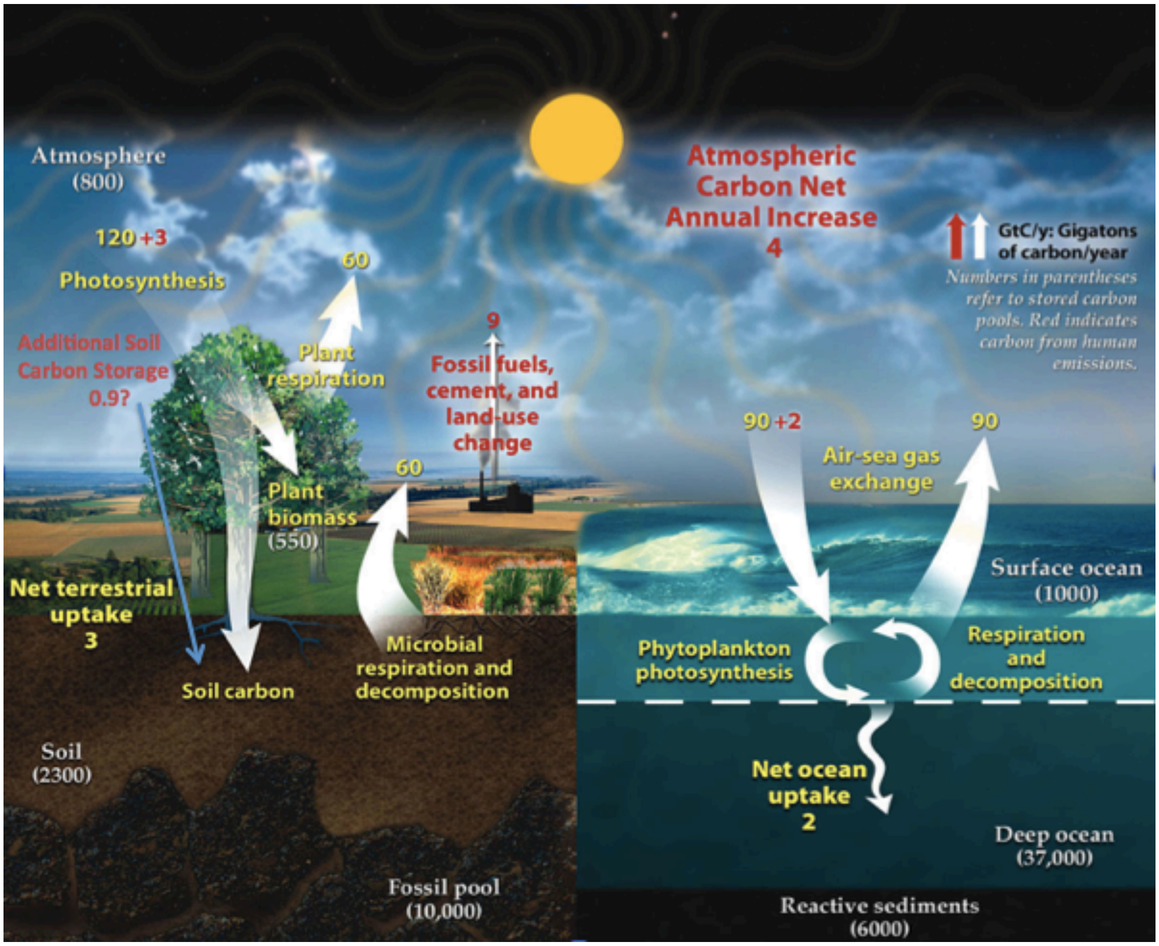
Appendix C: The Global Carbon Cycle and Future Supply vs Demand for Carbon Credits

Accurately estimating the future supply vs demand of carbon credits is crucial to understanding their long-term viability and impact. If demand greatly exceeds supply, credits will become highly sought after, more expensive, and greatly influence the behavior of nations and corporations. On the other hand, if supply greatly exceeds demand, the credits will become close to worthless.

Supply can be roughly estimated by multiplying global available area by the carbon storage capacity of that area. Assumptions must be made about how much area will go into carbon storage and what the average storage capacity per unit area of a certain land type is. A perfect model would separate as many environments as possible and accurately estimate the carbon storage potential of each area under the appropriate storage technique (AMP grazing, reforestation, reversion to native prairie, ect) as well as accounting for potential marine sequestration techniques and subsurface carbon capture and sequestration. This would be an enormous undertaking, so a couple rough estimates to give an idea of the general scale of carbon sequestration potential will be presented instead.

Demand for soil carbon credits can be very crudely equated to our current annual anthropogenic emissions, which is roughly **10 billion tons C/yr**. This is a reasonable estimate because of the Paris Accord's stated goal of achieving global anthropogenic carbon neutrality by mid-century. For that to occur, all emissions would have to be offset. This 10 billion tons C/yr number can therefore be taken as the high-end estimate for demand, with a possible low-end demand estimate being on the order of **4 billion tons C/yr,** or roughly the annual increase in atmospheric carbon after oceans and plants sequester the rest. One potential complication is that if another technology such as subsurface carbon capture and storage becomes economically viable, it will cut into the demand for soil carbon credits by increasing the availability of credits/offsets. However, soil and biological sequestration are currently the only economically viable way to sequester carbon on a large scale.

All but the most extremely optimistic estimates for global soil carbon storage potential have it falling significantly short of our current anthropogenic emissions pace. This means that in a future where carbon neutrality is a must, the demand for carbon credits generated from soil sequestration will greatly exceed supply. Carbon credits can therefore be expected to become increasingly valuable and eventually play a large role in the decision making process for corporations and countries in the coming years.



Note: The Global Carbon Cycle. Carbon pools are in white, natural fluxes are in yellow, and anthropogenic fluxes are in red. Additional soil carbon storage is dependent upon land management practices.
Source: Modified from U.S. DOE. 2008. *Carbon Cycling and Biosequestration: Report from the March 2008 Workshop*, DOE/SC-108, U.S. Department of Energy Office of Science. (p. 2-3)

Different Estimates of Carbon Sequestration Potential:

AMP Grazing Worldwide- In a recorded discussion about soil carbon storage, Russ Conser (of the Shell Gamechanger Program and the Standard Soil Project) estimated the carbon storage if all the world's grasslands were converted to the AMP grazing technique. He multiplied a 3 ton C/ha/yr estimate of storage potential (from Richard Teague and others' studies on the practice) and multiplied it by the 3.5 billion ha of grasslands in the world, coming out with **11 billion tons C/yr**, or 110 billion tons C/decade. This figure was deliberately made unachievably optimistic in order to convey the very real potential of soil carbon sequestration and the promise of AMP grazing in particular. It can't reasonably be reached because the 3 ton C/ ha/ yr estimate is a high-end one, the calculation doesn't take into account increased emissions from cattle produced methane, and it assumes that 100% of the world's grasslands can be converted, among other assumptions. Still, this thought experiment highlights that the sequestration potential for AMP grazing could be on the order of billions of tons of carbon per year if even a quarter of the world's grasslands were converted.

Rattan Lal- Lal is a researcher at Ohio State who has published extensively about the potential of global soil carbon sequestration. His 2004 study estimates a fairly conservative annual soil organic carbon sequestration potential at **0.9 (+/- 0.3) billion tons C/yr** above the current sequestration rate, a significant number but far short of expected demand. It takes into account multiple types of recommended management practices that could be implemented, global variability in soil type and land use, and the current degree of soil degradation. His 2010 and 2015 publications estimate the optimized annual soil and biological sequestration capacity globally, arriving at a global carbon sequestration potential of **1.2-3.1 billion tons C/yr** for croplands, grazing lands, and degraded lands, including both soil and biota storage. This number increases to **~2.5-5 billion tons C/yr** when forest carbon storage is included. These numbers are much larger than the 2004 total because they encapsulate all soil sequestration, not just what is additional to current rates, and include more biological storage than previously included (i.e. above ground forest storage).

While soil carbon sequestration is very unlikely to singlehandedly offset all anthropogenic greenhouse gas emissions, it certainly has the capacity to play a significant role. Even relatively conservative estimates of additional global carbon storage capacity, such as those made by Rattan Lal, give it the potential to offset around one quarter of current net atmospheric increase. When combined with other activities, such as investment in renewable energies and lowering energy consumption, this could be enough to stabilize or even decrease global anthropogenic emissions.

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