China’s Terrestrial Carbon Sink Potential:
A review of literature

Kalifi Ferretti-Gallon

February 2022

I. Executive Summary

The impacts of climate change over the last decade have intensified worldwide. In 2021, global disruptions of the Covid-19 pandemic were compounded by extreme weather and climate disasters. Devastating climate-related events over the last year included heatwaves, hurricanes, floods, and droughts experienced by countries across the world, amounting to well over 170 billion dollars of damage. As climate change impacts continue to add environmental, social, and economic pressures to a global system already under stress, it is becoming increasingly important to reduce greenhouse gas emissions. ‘

By the end of COP26, 151 countries revised or submitted new nationally determined contributions (NDCs) to a global reduction of emissions. China revised its NDC to include new goals for their emissions peak and net-zero targets. However, there is concern that the revised objectives and climate strategies of the world’s largest emitting country might not be sufficient to reduce global temperatures to 1.5°C above pre-industrial levels. Fortunately, recent efforts to restore and protect China’s terrestrial biomes have improved the country’s capacity to reduce its net emissions.

This report provides a review of literature on the capacity of China’s terrestrial ecosystems to store carbon and remove carbon dioxide for each major terrestrial biome: forests, grasslands, croplands, shrublands, and wetlands. This analysis concludes with a list of policy recommendations and opportunities for each biome to enhance China’s capacity to store carbon and exceed its current targets.

Based on the review of literature, four key takeaways are identified:

- **Carbon sequestration plays a significant role in China’s carbon peaking and carbon neutrality.** The degree to which different biomes offers carbon storage and sequestration potential varies greatly, with China’s forests providing the majority of soil and vegetation carbon storage (38%), followed by grasslands (30%), croplands (19%), shrublands (8%), and wetlands (5%).
- **China’s forests shifted from source to sink; currently representing about 56% of total terrestrial sequestration.** Existing programs incentivizing afforestation and reforestation in China is expected to increase forests capacity to remove and store carbon, and substantially expanding these initiatives to could significantly offset the countries predicted annual emissions.
- **Managing in China to improve yields could also enhance sequestration potential.** Croplands in China store about 1/5th of its terrestrial carbon. Sequestration through sustainable soil management to improve annual yields could also function to significantly increase carbon uptake.
- **Grasslands and shrublands don’t hold as much vegetation carbon relative to forests but still play a vital role.** Both biomes have diminished in area due to conversion to other land uses, but have a high potential of carbon sequestration and retention of properly restored.

- **Protecting wetlands will be important for mitigating major GHG releases.** While wetlands represent the smallest proportion of China's terrestrial carbon storage, they are an important storage for carbon dioxide as well as methane and are vulnerable to climate impacts and land use change that could prompt their release
- **A comprehensive system to track trends in China's terrestrial carbon storage and sequestration rates is strongly recommended.** China's terrestrial biomes are important for offsetting the country's emissions and contributing to global efforts to mitigate climate change. However, their capacity to remove and store carbon is influenced by variables specific to each biome. A system that tracks these trends will improve analysis and inform better land sector policies in China.

Table of Contents

List of Tables

List of Figures

II. Introduction

China and Climate Change

Since the 2015 Paris Agreement, country pledges and policy changes to address climate change continue to be insufficient to limit global warming to below 1.5°C above pre-industrial levels this century. Despite an unprecedented drop of 5.4% in 2020 due to the COVID-19 pandemic, global carbon dioxide emissions were estimated to have bounced back by 4.9% in 2021 (Friedlingstein, et al. 2021). Even with the most recent climate pledges, along with other mitigation efforts, global temperatures are anticipated to rise to 2.7°C by 2100 (UNEP 2021).

While many developed countries significantly contribute to greenhouse gas (GHG) emissions, China continues to be the world's largest emitter of GHGs, accounting for almost a third (27%) of all emissions according to recent estimates (Larsen, et al. 2021). With a steadily growing economic sector largely dependent on coal, China's CO2 emissions are increasing at their fastest rate in more than a decade (Myllyvirta 2021). China's own climate concerns have grown as the domestic impacts of climate change have not been insignificant. Studies have attributed a recent decline in crop yields, considerable terrestrial and marine biodiversity reductions, and extreme weather events to climate change (Xie, et al. 2020, Yang, Xiahua and Yin 2021, Kang, et al. 2021, Kang and Eltahir 2018).

China's Climate Pledge

Acknowledging the existential threat posed by climate change and incentivized by better energy management, China has adopted international commitments and implemented domestic policies to decouple its emissions from its GDP. In 2016, China signed the Paris Agreement, pledging to cut carbon emissions by 65% per unit of GDP by 2030, compared with 2005 levels, to increase their dependency on non-fossil fuels to 20%, and to increase forest stock volume by 4.5 billion cubic meters. More recently, in 2021, China revised its Nationally Determined Contribution (NDC), raising its target share of non-fossil energy to 25%, and increasing its target forest stock volume to 6 billion cubic meters. The country has further pledged to aim for peak emissions by 2030 and carbon neutrality by 2060.

Despite changes implemented by countries to achieve targets outlined in their NDCs, an increasing trend in global emissions underscores their inadequacy. This is particularly true for China, where, despite the economic impacts of the COVID-19 pandemic, emissions actually continued to increase by about 1.5% in 2020 (Myllyvirta 2021). While China's improved NDC revisions indicate its government's commitment to sustained climate action, the targets remain highly insufficient. Projections indicate that by 2030, even with improved targets, China is on its way to producing nearly twice the amount of estimated maximum emissions needed to limit global warming to 1.5°C (CAT 2022). Improving China's capacity to significantly contribute to climate mitigation efforts will require energy transition in its power, transportation, and industry sectors. This capacity can be vastly enhanced by also focusing on better land-use management.

Terrestrial Carbon and the Emissions Gap

With the policies that are currently in place, it is estimated global efforts will limit warming to 2.8°C by the end of the century. The new and updated NDCs are projected to reduce global emissions by 7.5%, whereas 55% is required to limit warming to 1.5°C (UNEP 2021). For climate change to stabilize, global anthropogenic net emissions must reach net-zero, implying a shift towards negative emissions over time.

While cutting fossil fuel consumption is a direct way to reduce carbon emissions, better management of terrestrial biomes offers countries the opportunity to sequester carbon, offset remaining positive emissions, and reach negative emissions targets.

It is estimated that an accumulation of carbon in the global land sector accounts for the removal of 3.61 Pg C per year, amounting to almost 34% of total anthropogenic emissions (Keenan and Williams 2018). Understanding the capacity of a country's land sector to help meet climate goals is crucial, as different terrestrial biomes offer carbon storage and removal to varying degrees. Forests account for approximately 46% of the world's terrestrial carbon stocks, followed by tropical savannas and grasslands (26%), wetlands (10%), deserts (8%), and croplands (5%). Across most biomes, soils hold much more carbon (81%) than the biome's vegetation (19%) (Watson, et al. 2000).

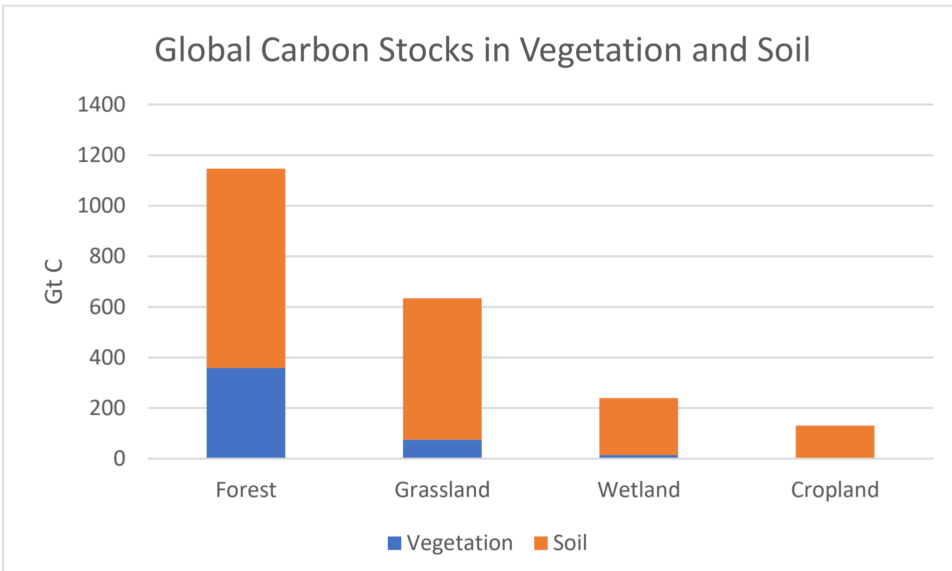

Figure 1 Global carbon stocks per terrestrial biome
(Adapted from IPCC Report on Land Use, Land-Use Change and Forestry) (IPCC 2007))

Therefore, in order to meet its climate targets, it is necessary for China to include land management in climate planning and policy development. Including a pledge to enhance forest stocks along with its revised NDC is a promising start. Identifying where the country stores its terrestrial carbon, which biomes are contributing to carbon sequestration, and which biomes are vulnerable to dynamic carbon flux will be key to ensuring China can meet, if not surpass, its carbon objectives.

III. Objectives and Approach

Context: China's Land Use

China ranks fifth among countries with the most forested area and is counted among the world's most biodiverse countries. It boasts a vast land area with an abundance of vegetation and is widely acknowledged to be among the most significant contributors to global carbon uptake (Jiang, et al. 2021).

It is estimated that its forestry sector sequesters about 649.43 million tonnes of C02 annually, accounting for 5% of the country's total annual emissions (Ritchie and Roser 2020).

China's current robust forest landscapes are a consequence of a series of efforts to address decades of forest loss. After the establishment of the People's Republic of China in 1949, the country's forestry sector began harvesting timber intensively to fuel its industrializing economy and growing population. By 1993, it had lost about a third of its forest area, leaving the remaining forests significantly degraded. Simultaneously, uncontrolled grazing and poor rangeland maintenance caused extensive loss of grassland and desertification (Xu, et al. 2006). The resulting vegetation loss and degradation of China's natural landscapes culminated in devastating floods in the Yangtze River basin in 1998.

In response, over the last four decades, China has implemented a series of nationwide ecological restoration projects and major programs to increase its tree cover, reduce degradation, create green spaces, and conserve biodiversity. Notable programs include The Three-North Shelterbelt Program which aims to build a 4500 km wall of trees through the Gobi desert by 2050, The Grain for Green Program which aims to convert crops to forests on sloped terrain to mitigate soil erosion, the Natural Forest Conservation Program which conserves natural forests through logging bans and incentive afforestation, and the Wildlife Conservation and Nature Reserve Development Program designed to promote new nature reserves, among others (Wang, et al. 2021). In addition to restoring these landscapes, China also made concerted efforts to introduce an expansive network of protected areas that now account for about 18% of its total land area (Chen 2021).

These policies were significantly effective in recovering vegetation nationwide. It is estimated that between 2000-2010, 1.6% of China observed a net gain in tree cover as well as an increase in net primary productivity of 0.91 Tg of carbon (Viña, et al. 2016). It is now estimated that China is experiencing forest transition, recording net annual forest gain in recent years rather than net annual forest loss (Zhai, et al. 2017).

Objective

Given China's growing wealth of terrestrial carbon, its land sector has significant potential to help the country meet its climate targets. The overarching goal of this report is to provide insights into key opportunities for China to restore, protect, and enhance this capacity. More specifically, this report will endeavor to identify potential opportunities to protect carbon stocks, increase sequestration potential, and avoid significant emissions releases.

The following is a review of all recent studies on terrestrial biomes that store carbon in China. Building on the overarching goal, the objectives of this report are to:

- Evaluate current carbon storage across different biomes in China
- Identify and compare sequestration potential of each biome
- Determine the vulnerability of each biome to carbon fluxes.
- Provide recommendations on how China's land sector can enhance its climate targets.

Methods

This literature review sources contextual information and data from available research and draws on relevant academic journal articles and published databases of carbon estimates in China. The major landscape categories under review are forests, grasslands, wetlands, croplands, and shrublands as these were identified to overlap consistently across studies. The studies were identified using the databases Web of Science and Google Scholar. Search parameters were limited to papers whose title, abstract, or keywords referred to “China”, and “terrestrial”, “land” or “biome” in combination with “carbon storage”, “carbon budget”, “carbon balance”, “carbon stock”, and “carbon sequestration” The following criteria were adopted to ensure the quality of the selected literature:

- Relevancy: Ensuring the paper was published within a time frame that keeps its conclusion relevant to the current context
- Objectivity: Ensuring the study is an objective analysis of the potential of China’s terrestrial biomes to enhance its climate mitigation capacity
- Reliability: Ensuring the paper is peer-reviewed or published from a renowned source

Data sources on the effects of carbon stocks and sequestration were assembled from studies published from 1994-to 2021. The search yielded 49 studies sourcing data through national inventories, published data, and published literature investigation (See Annex A). Vegetation and soil carbon stocks and annual sequestration values were presented by original studies in various units. All values were converted to Pg C. If the study itself was a meta-analysis of multiple studies to inform an aggregate value, studies that were used multiple times across analyses were removed to ensure values were weighted equally. Changes in carbon stocks over time were ascertained from studies evaluating carbon stocks in different time periods. Where studies overlapped temporally, the median value was used to inform trends over time. It should be noted here that each study used different means to evaluate carbon storage, and therefore the temporal analysis aspect of this literature review should be viewed as an insight into overarching trends rather than an actual account of unit changes.

IV. Analysis

China’s Terrestrial Carbon Pools and Trends

The following is an analysis of the current state of carbon storage in each biome based on trends over time and current estimates aggregated from recent literature. Based on the most recent estimates included in this study (Table 1), the total terrestrial carbon storage in the five biomes accounted for 84 Pg C, of which 17% (14.5 Pg C) was found in vegetation and 85% (70.3 Pg C) found in soil. It should be noted here that estimates varied widely, in both total terrestrial carbon estimates and proportional allocations to vegetation and soil. This difference can be explained by the biomes included in each analysis (wetlands were sometimes excluded as “terrestrial”), different approaches to land use classification leading to variability in land area covered, and different approaches to aboveground biomass measurements (Wang, et al. 2020).

Table 1 Recent estimates of China's total terrestrial carbon

	Soil	Vegetation	Total
Xu et al 2018	84.55	14.60	99.15
Tang et al 2018	74.98	14.29	89.27
Fang et al. 2018	65.69	13.09	78.78
Wang et al. 2021	37.27	18.19	55.46

Terrestrial carbon stocks in China are largely distributed between five major biomes. Based on this literature review, it is estimated that forests, grasslands, croplands, shrublands, and wetlands store 31.76 Pg C, 25.38 Pg C, 16.32 Pg C, 7.02 Pg C, and 3.915 Pg C, respectively (Figure 2). While it is clear that some biomes store more carbon than others, each has important value for restoring and maintaining carbon. Forests are an important form of biomass carbon storage, grasslands are key for soil carbon storage, shrublands can be used for enhanced carbon sequestration, existing croplands have the potential for increasing soil carbon uptake in tandem with increased productivity, and wetlands should be monitored for potential GHG emissions and managed accordingly. The following is a review of trends and latest estimates for each biome.

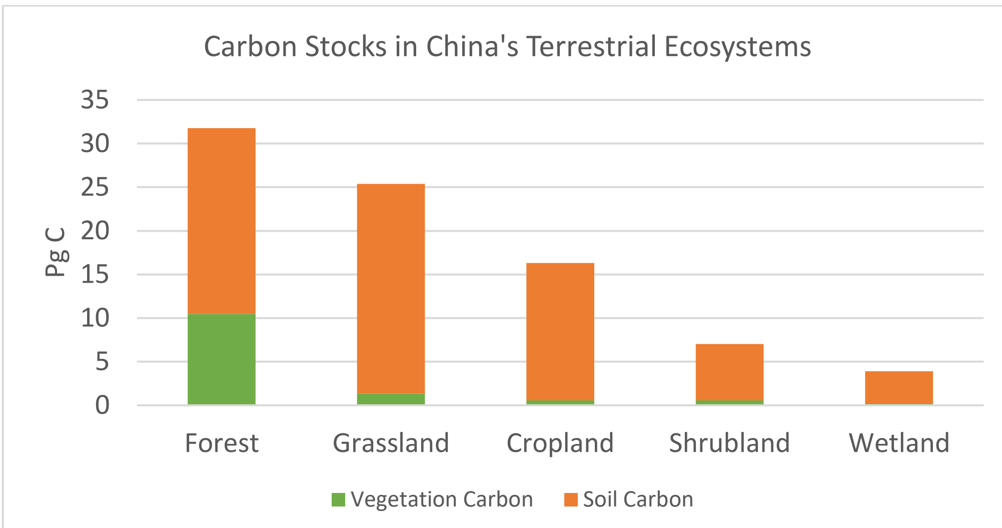

Figure 2 China's terrestrial carbon stocks

Forests

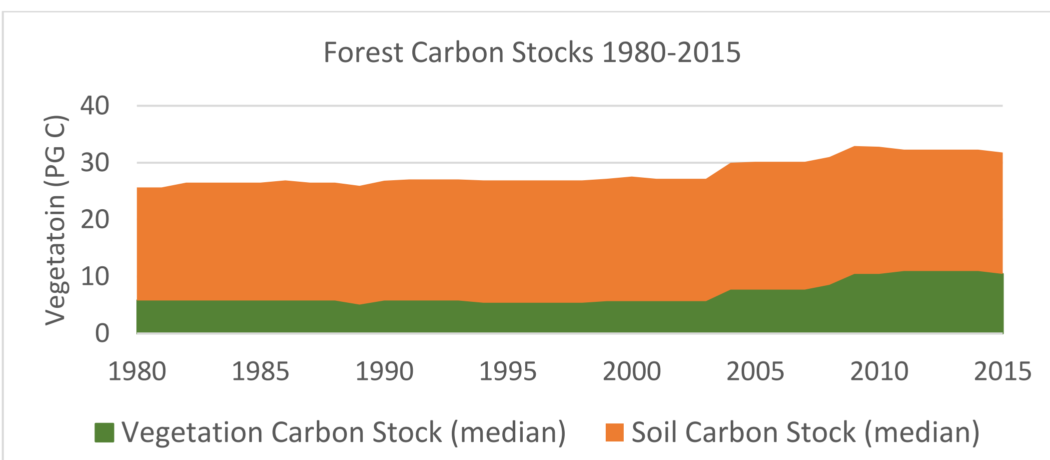

Figure 3 China's forest carbon stocks

Forest ecosystems are a source of vital services including water regulation, biodiversity protection, improved air quality, and carbon storage. They are also the biome with the most potential for carbon sequestration, leading the IPCC to conclude that increasing forest area by 950 million ha will be necessary to limit global warming by 2050. As a country with an extensive and growing forest area, China is well-positioned to make this happen. Based on estimates of this study forests currently represent China's largest terrestrial carbon sink, accounting for around 38% (31.8 Pg C) of China's terrestrial carbon stocks.

Over the last 70 years, the management of China's forests changed significantly and the biome transformed from a carbon source to a carbon sink. After nationwide policies were implemented to restore forest ecosystems and to increase the country's forest cover, China experienced a steady rise in forest carbon storage (Figure 4). These efforts resulted in the sequestration of 4.68 billion tons of C02 from 1980-2005 (Jin, Yi and Xu 2020). Continued management and policy implementation have resulted in the increase of the country's vegetation carbon storage by 36% (Zhang, et al. 2020).

China's afforestation efforts now account for about 43% of China's forests (Zhang, et al. 2020). In total, it is estimated that China's forests sequester the equivalent of ~15% of the country's industrial C02 emissions (Jin, Yi and Xu 2020). With current policies in place, it is estimated that China's forest carbon sinks will be approximately 0.6 gigatons of CO2 by 2050 (Zhang and Chen 2021). China's forest carbon stocks could be enhanced to improve carbon storage and sequestration and help the country offset its predicted future emissions. Most studies recommend improving China's forest density, expanding forested areas through reforestation and afforestation, and avoiding deforestation and forest degradation. Finally, sustaining existing efforts to improve China's forests is key, as one study indicates that continuing the Grain for Green Program alone could offset China's total projected carbon emissions in 2050 (Deng, et al. 2017).

Grasslands

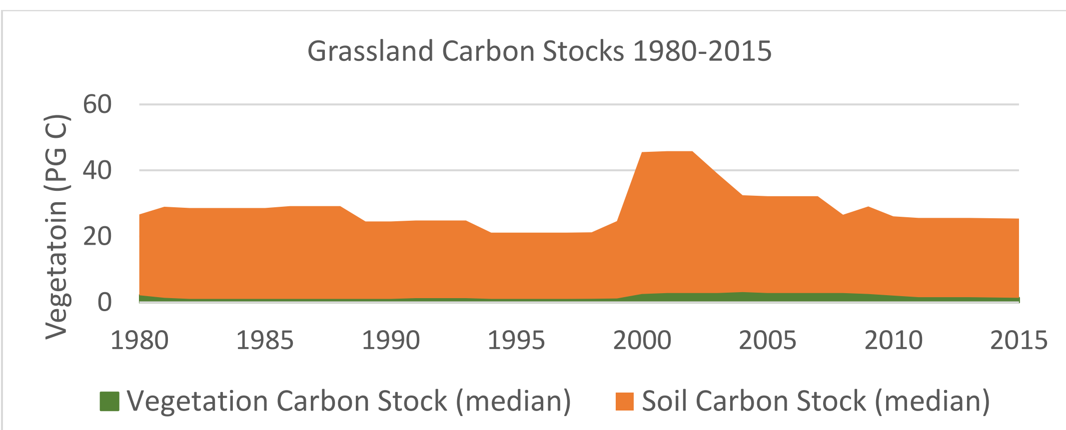

Figure 4 China's grassland carbon stocks

Grasslands account for 1/3 of the global terrestrial carbon stock, second only to forests (Figure 1). Carbon stocks in grasslands are predominantly (~89%) held in the organic matter contained in its soil. Grasslands are an important source of carbon storage, but also could be a source of emissions. As climate warming accelerates the decomposition of soil organic matter, carbon is increasingly released from soils, making grasslands a potential net source of emissions.

Grasslands are the dominant landscape in China, accounting for around 40% of the country's total area, and are an important component of the world's grassland carbon stocks (Li, et al. 2020). Based on published data included in this analysis, grasslands account for 30% of all terrestrial carbon stocks in China (27.84 Pg C) (Figure 3), with soils comprising 28.34 Pg C and vegetation accounting for 1.35 Pg C. It should be noted here that large uncertainties remain in the extent of grassland carbon in China. Estimates for grassland carbon in China included in this study ranged widely from 16.89 Pg C – 59.5 Pg C for all grassland carbon, 0.56-4.7 for vegetation, and 12.93-56.3 for soils. This is likely to do with varying measurement approaches and land use classification.

Over the last several decades, China's grasslands have experienced periods of degradation and restoration (Figure 4). It is estimated that from the 1980s to the 2000s, the area of degraded grassland increased by 3 million hectares (M ha) due to over-grazing, conversion to croplands, and poor pest management (Xie, et al. 2007), resulting in reduced capacity to store carbon. China's government implemented policies to help improve grassland ecosystems resulting in an increase of 1.1 Mg C per ha of grassland area by the 2000s. Despite this, grasslands are estimated to have acted as a weak source of carbon emissions from 2001-2010, as the expansion of urban areas and cropland decreased grassland area in all regions by ~7% (Lai, et al. 2016, Yang, Xiahua and Yin 2021). In the last decade, renewed efforts were introduced to mitigate grassland degradation and related emissions. Studies estimate that continued restoration of grassland areas can increase plant biomass by almost 30% (Song, et al. 2021).

Croplands

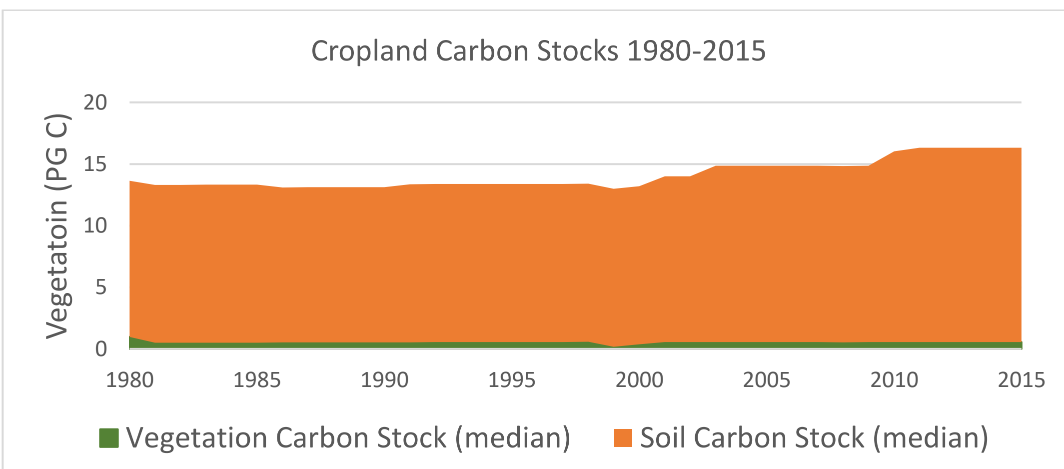

Figure 5 Cropland carbon stocks in China

A large portion (~171 Mha) of China's land area is comprised of cropland used to help feed 1.4 billion of its people (Tang, Zhao and Bai 2018). Croplands in China also play an important role for global food security, providing about 30% of the global production for paddy rice, 21% for wheat, and 18% for corn (Wang, et al. 2022). Croplands in China account for about 19% (14.67 Pg C) of the country's terrestrial carbon stocks. The estimates for cropland carbon storage over the last few decades varied widely (7.91-19.71 Pg C for all cropland carbon, 0.49 – 2 Pg C for vegetation carbon, and 4-18.73 Pg C for soil carbon).

Carbon storage in soils is measured by depth, and the values for Pg C shift depending on the soil layer of focus. Studies measuring soil organic carbon at depths of 1 meter were included in the study for comparative purposes.

Prior to 1980, China's underdeveloped rural economy was unable to support its agricultural sector leading to low input of organic matter to boost its productivity, and therefore a lowered capacity to store carbon. As China's economy strengthened over the next few decades, its population no longer relied on the removal of organic matter for energy needs and improved agricultural management by introducing recycled organic material into the soils. A series of agricultural policies in the 1980s focused on upgrading soil fertility and enhancing rain yield increased the quality of soils. By 2004, China's farmland experienced an increase of 0.472 Pg C (Xie, et al. 2007). In recent years, the government introduced incentives for farmers to increase yield by adopting GHG reduction practices like returning crop residues to soils instead of burning them (Han, et al. 2017). Increased agricultural productivity also led to increased accumulation of vegetation carbon stock (Figure 5). However, recent changes in climate have impacted crop growth and productivity, leading to an annual decline in productivity and carbon stock (Tao, Palosuo and Makipaa 2019). If better management practices were put in place, it is estimated that soil organic carbon in China's croplands could increase by 0.63% per year (Tao, Palosuo and Makipaa 2019).

Wetlands

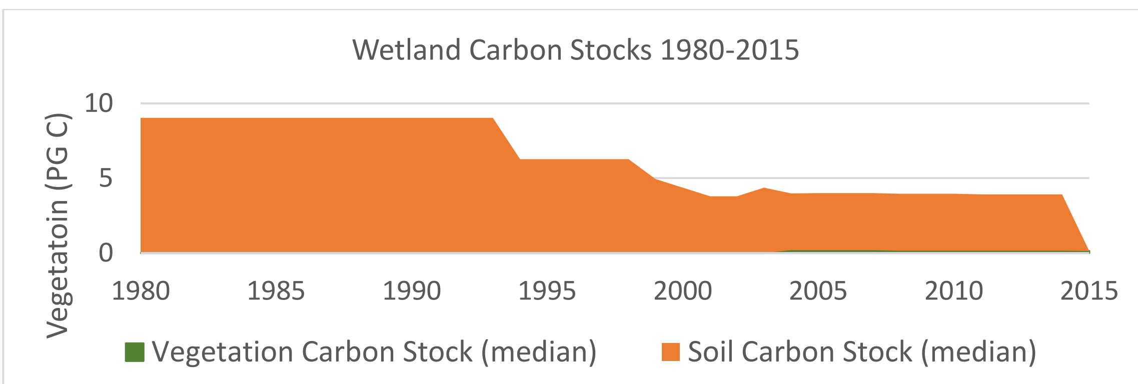

Figure 6 China's wetland carbon stocks

While wetlands represent the smallest proportion of the world's terrestrial carbon content (Fig 1), they boast some of the highest values for ecosystem services and biodiversity protection. Wetlands also play a key role in the global carbon cycle. Wet conditions in this biome limit the availability of oxygen and slow the rate of anaerobic composition. It is estimated that wetlands have accumulated 240 Gt C in their soils (IPCC 2007). Wetlands are also a source of GHG emissions, producing methane within its anaerobic soil conditions. Changes in wetland areas and related impacts on emissions are therefore a source of climate concern.

Wetlands are estimated to occupy about 1.7% of China's terrestrial ecosystems (Xu, Yu and He 2019). The studies included in this analysis estimate that wetlands in China represent 5% (~4 Pg C) of the country's stored terrestrial carbon. It should be noted here that estimates of carbons storage in wetlands varied widely according to the definition of "wetland". A more recent study estimated that wetland carbon stock could be as high as 16.78 Pg C (Xiao, et al. 2018). Despite their smaller land area and carbon representation, this biome poses a significant challenge to China's emissions management. Over the last few decades, soil carbon storage in China's wetlands declined (Figure 6). Lu et al 2021 estimated that the area of wetland in China decreased by half between the 1980s and the 2000s (Lu, et al. 2021). Furthermore, studies also indicate that, within this same period, wetlands acted as substantial net carbon sources. Over the last few decades, China has experienced diminishing water levels and declining areas of wetlands as a result of urban and agricultural expansion, resulting in decreased soil organic matter content and a release of CO2 and Ch4 (Xu, Yu and He 2019). Wetland loss in the last few decades has actually decreased methane release by 50%, however, anticipated climate changes could strengthen national methane emissions (Weki and Wang 2017)

Shrublands

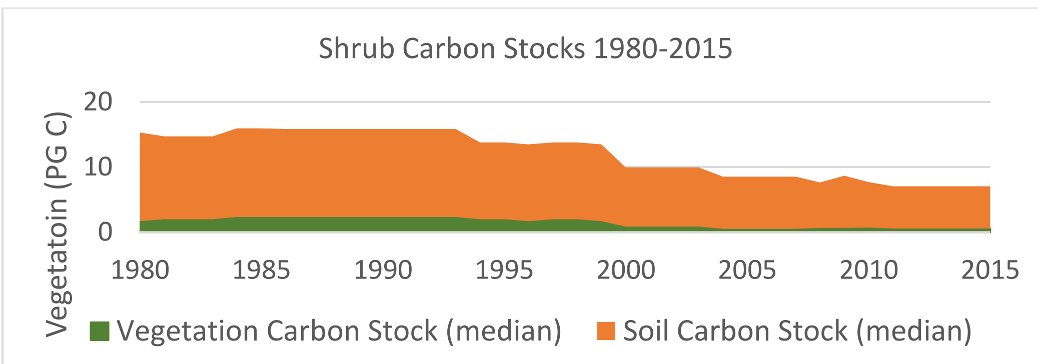

Figure 7 Shrubland carbon stocks in China

Shrubland ecosystems form another important terrestrial biome that contributes to carbon sequestration, among other ecosystem services. Aboveground woody biomass in arid areas is studied much less as it is sometimes considered a transitional stage of forest succession and it has much less vegetation carbon relative to forest ecosystems. However, shrublands are gaining attention for their contributions to inter-annual terrestrial carbon variability (Fusco, et al. 2019).

In China, shrublands are widely distributed and play a key role in the country's carbon budget. Based on the estimates included in this analysis, shrublands account for 8% (~ 7 Pg C) of China's terrestrial carbon stocks. These estimates indicate a decline in the capacity of China's shrubland to store carbon (Figure 8). This is likely due to the fact that many shrubby areas have been identified as suitable for planting trees and other crops. From 2001-2012, one study estimates that about 18% of shrubland was converted to forests and 14% was converted to cropland (Li, et al. 2020).

Shrublands in China are characterized by fast growth, are highly adaptable to arid and semi-arid regions within China, are relatively high in above-ground biomass, and offer other benefits for mitigating soil erosion and preserving biodiversity. This is an understudied ecosystem that could play a key role in enhancing China's terrestrial carbon storage capacity.

Changes in China's terrestrial sequestration and dynamic changes

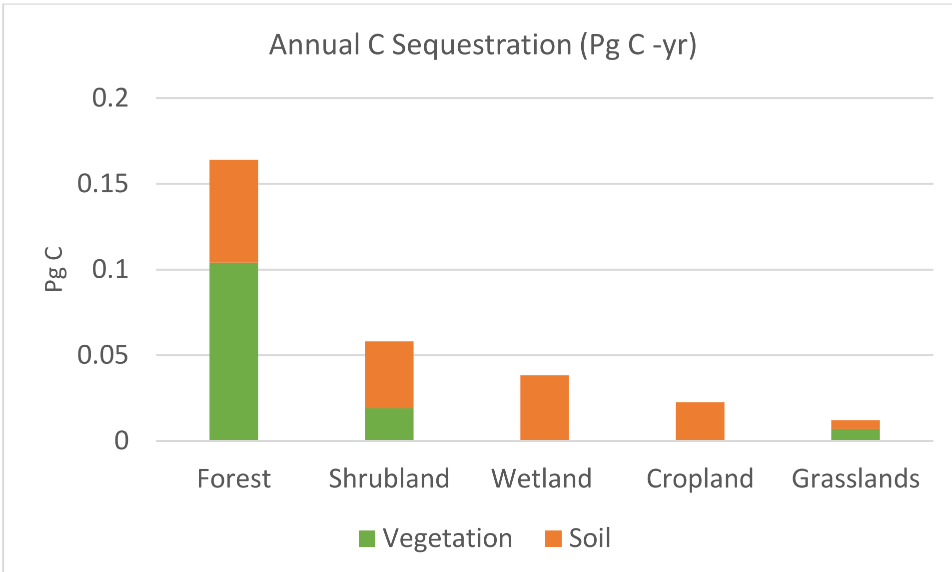

Figure 8 Annual carbon sequestration by terrestrial biome in China

Terrestrial biomes can be a net sink for CO2 emissions, but they can also act as a source. Net negative forestry change, degraded grasslands and crops, and emissions from poor soil management contribute significantly to this estimate. Annual sequestration potential varies widely between China's biomes (Figure 8).

Before 1980, China's forests functioned as carbon sources, with an annual emission rate of 22 Tg C per year (Fang, et al. 2001). As previously mentioned, large-scale restoration projects transformed the country's forests into a significant sink. While fires certainly pose a risk of forest biomes changing to net carbon sources, current management practices in China are also ensuring this biome continues to be a major source of carbon sequestration. Based on studies included in this analysis, forests sequester around 164 Tg C per year (Figure 8), with the majority sequestered in forest biomass followed by soils.

While estimates of this study indicate grasslands are a net carbon sink, some studies have suggested they are carbon neutral or act as a carbon source. One study concluded that, over the last few decades, grasslands in China have gradually shifted from being a net carbon sink to being carbon neutral, to becoming a carbon source (Yang, Xiahua and Yin 2021). Emissions from grasslands are largely due to human management of these areas for conversion to croplands and grazing areas. Conversion of cropland back to grassland does not necessarily guarantee increased carbon stock, as agricultural soils that are irrigated often hold more carbon than dryer grasslands. However, ensuring the restoration is permanent will likely secure higher carbon stocks, as carbon stocks are reduced during the early stage of grassland restoration and enhanced during later stages (Song, et al. 2021).

Croplands in China are not only significant for soil carbon storage, they are also an important potential source for carbon sequestration potential Estimates in this analysis indicate annual carbon sequestration in cropland soils amount to around 22 Tg C. Carbon uptake in China's croplands varies by region. Heilongjiang Province, for instance, has been identified as an area with decreasing soil stocks (Yang, Xiahua and Yin 2021). Variation in cropland carbon uptake is largely due to soil quality; areas high in soil organic carbon are both able to be more productive and sequester more carbon. Because cropland carbon sequestration is correlated with productivity, studies advise promoting better sustainable soil management practices in middle and low yield farms (Tao, Palosuo and Makipaa 2019). Cropland sequestration potential in China is negatively impacted by climate change. However, management practices can enhance China's cropland carbon uptake potential despite these impacts. Sustainable soil management practices that increase carbon uptake include reduced tillage/no-tillage, straw returning, and organic fertilizer input (Yang, Xiahua and Yin 2021). If these practices were implemented over the next 20 years, croplands in China could conceivably increase this biome's annual sequestration potential by 59% (Wang, et al. 2022)

Overall, wetlands in China are considered to be carbon sinks. Our study estimates that this biome sequesters around 38 Tg C per year. However, managing wetland areas depends on wetland type as each has a high degree of variability. Annual sequestration rates are highest in mangrove and coastal areas and low for peatlands and lakes. However, peatlands and lakes have higher sequestration potential if restored (Xiaonan, et al. 2008). While peatlands constitute the smallest wetland carbon stock, they are becoming of increasing concern. As previously mentioned, peatlands can quickly begin emitting GHG if subject to drying climate or land-use change. It should be noted here that estimates for wetlands in China have a high degree of uncertainty, as plant species, soil depth and conditions vary widely between each sub-type..

According to estimates in this study, shrublands function as an overall carbon sink, sequestering an estimated 58 Tg C per year. However, shrubland degradation could turn these systems into net carbon sources, counteracting their total sequestering potential. The capacity of this terrestrial carbon sink varies by region, with higher values observed in southeast China and southwest China (Tian, et al. 2011). This suggests management practices in areas with high sequestration should be maintained, and restoration practices in other areas with low sequestration should be introduced.

V. Policy Recommendations

Unlike most sectors that contribute to global emissions, the land sector offers opportunities to reduce emissions, increase carbon removal from the atmosphere, and meet other sustainability objectives (e.g. protecting biodiversity and ensuring the provision of ecosystem services). Over the last decade, the concept of "Nature-based solutions" (NbS) has been gaining ground as means of achieving biodiversity conservation, protecting ecosystem services, as well as climate change mitigation and adaptation objectives (Pauleit, et al. 2017). It is important to note that increasing carbon content in China's terrestrial ecosystems should be part of a comprehensive effort to restore and enhance the integrity of these ecosystems. Studies have noted that China's past efforts to increase forest cover by converting croplands to tree plantations led to a significant loss of native forests (Hua, et al. 2018). Simply increasing vegetation cover without considering the quality of these natural landscapes could enhance land degradation and undermine the provisioning of important ecosystem services.

Based on this literature review, it is clear that China has a wealth of carbon storage and sequestration potential available in its extensive terrestrial biomes. These can be vastly improved with effective land use policies and management practices. The following recommendations have been identified to better restore, protect and manage each biome:

- Forests:
  - Protect carbon in existing natural and planted forested areas
  - Manage existing planted forested areas to improve biomass densities
  - Expand reforestation and afforestation projects
- Grasslands:
  - Protect existing grassland from conversion to other land use and from degradation by grazing
  - Ensure restored grassland areas are permanent, thereby enhancing their storage capacity relative to the capacity during the initial period of restoration
- Cropland:
  - Increase crop productivity in key areas by expanding irrigation, improving soil organic matter inputs, and using modern cultivars
  - Incentivize conservation practices that include conservation practices such as low/no-tillage and crop straw return
  - Support programs that promote better management practices in middle and low yielding farms
- Wetlands:
  - Introduce management practices that preserve carbon stocks in coastal wetlands
  - Restore wetland areas to improve this biome’s sequestration potential
  - Avoid GHG emissions from wetland areas by protecting marshes from conversion to other land uses
- Shrublands:
  - Restore degraded areas of shrubland to improve their carbon storage and sequestration potential
  - Protect shrublands from conversion to agriculture or urban areas

While cutting its fossil fuel emissions remains the primary approach to limiting global warming, China’s terrestrial ecosystems are important for offsetting the country’s emissions. Each biome has the capacity to remove and store carbon to varying extents influenced by a wide range of variables. It is highly recommended that a system be developed to track trends in carbon storage, sequestration, and potential emissions across each biome. Understanding how these ecosystems change and the drivers of those changes is fundamental for developing land management policies that are effective in preserving ecosystem services and enhancing carbon stocks.

Bibliography

CAT. 2022. "China." *Climate Action Tracker.* February 18. https://climateactiontracker.org/countries/china/.

Chen, Haojie. 2021. "The ecosystem service value of maintaining and expanding terrestrial protected areas in China." *Science of the Total Environment* 146768.

Deng, Lei, Shuguang Liu, Dong Gill Kim, Changhui Peng, Sandra Sweeney, and Zhouping Shangguan. 2017. "Past and future carbon sequestration benefits of China's grain for green program." *Global Environmental Change* 13-20.

Fang, Jingyun, Anping Chen, Changhui Peng, Shuqing Zhao, and Longjun Ci. 2001. "Changes in Forest Biomass Carbon Storage in China Between 1949 and 1998." *Science* 2320-2322.

Friedlingstein, Pierre, Matthew W. Jones, Michael O'Sullivan, Robbie M. Andrew, Dorothee C. E. Bakker, Judith Hauck, Corinne Le Quéré, et al. 2021. "Global Carbon Budget 2021." *Earth System Science Data* UNDER REVIEW.

Fusco, Emily J., Benjamin M. Rau, Michael Falkowski, Steven Filippeli, and Bethany A. Bradley. 2019. "Accounting for aboveground carbon storage in shrubland and woodland ecosystems in the Great Basin." *Ecosphere* e02821.

Han, Daorui, Martin Wiesmeier, Richard T. Conant, Anna Kuhnel, Zhigang Sun, Ingrid Kogel-Knabner, Ruixing Hou, Peifei Cong, Rubiao Liang, and Zhu Ouyang. 2017. "Large soil organic carbon increase due to improved agronomic management in the North China Plain from 1980s to 2010s." *Global Change Biology* DOI: 10.1111/gcb.13898.

Hua, Fangyuan, Lin Wang, Brendan Fisher, Xinlei Zheng, Xiaoyang Wang, Douglas Yu, Ya Tang, Jianguo Zhu, and Davide Wilcove. 2018. "Tree plantations displacing native forests: The nature and drivers of apparent forest recovery on former croplands in Southwestern China from 2000 to 2015." *Biological Conservation* 113-124.

IPCC. 2007. *Special Reports: Land Use-Land Use Change and Forestry.* Accessed January 18, 2022. https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=3.

Jiang, Lifen, Liang Junyi, Lu Xingjie, Enqing Hou , Forrest M. Hoffman, and Yiqi Luo. 2021. "Country-leve lland carbon sink and its causing components by the middle of the twenty-first century." *Ecological Processes* 10 (61).

Jin, Lu, YuanYuan Yi, and Jintao Xu. 2020. "Forest carbon sequestration and China's potential: the rise of a nature-based solution for climate change mitigation." *China Economic Journal* 200-222.

Kang, Bin, Gretta T. Pecl, Longshan Lin, Peng Sun, Peidong Zhang, Yuan Li, LinLin Zhao, et al. 2021. "Climate Change impacts on China's marine ecosystems." *Reviews in Fish Biology and Fisheries* (Reviews in Fish Biology and Fisheries).

Kang, Suchul, and Elfatih A. B. Eltahir. 2018. "North China Plain threatened by deadly heatwaves due to climate change and irrigation." *Nature Communications.*

Keenan, T.F., and C.A. Williams. 2018. "The Terrestrial Carbon Sink." *Annual Review of Environment and Resources* 219-243.

Lai, Li, Xianjin Huang, Hong Yang, Xiaowei Chuai, Mei Zhang, Taiyang Zhong, Zhigang Chen, Yi Chen, Xiao Wang, and Julian R. Thompson. 2016. "Carbon emissions from land-use change and management in China between 1990 and 2010." *Science Advances* e1601063.

Larsen, Kate, Hannah Pitt, Mikhail Grant, and Trevor Houser. 2021. *China's Greenhouse Gas Emissions Exceeded the Developed World for the First Time in 2019.* Rhodium Group.

Li, Hanwei, Juhua Ding, Jiang Zhang, Zhenan Yang, Bin Yang, Qihuan Zhu, and Changhui Peng. 2020. "Effects of Land Cover Changes on Net Primary Productivity in the Terrestrial Ecosystems of China from 2001 to 2012." *Land* 10.3390/land9120480 .

Li, Linghao, Jiquan Chen, Xingguo Han, Wenhao Zhang, and Changliang Shao. 2020. "Overview of Chinese Grassland Ecosystems." In *Grassland Ecosystems of China*. Singapore: Springer.

Lu, Mingzhi, Yuanchun Zou, Zicheng Yu, ming Jiang, Lianxi Shen, and Xianguo Lu. 2021. "Anthropogenic disturbances caused declines in the wetland area and carbon pool in China during the last four decades." *Global Change Biology* 3837-3845.

Myllyvirta, Lauri. 2021. *Analysis: China's carbon emissions grow at fastest rate for more than a decade.* Carbon Brief.

—. 2021. *China's five-year plan: baby steps towards carbon neutrality.* March 5. Accessed February 18, 2022. https://energyandcleanair.org/china-14th-five-year-plan-carbon-neutrality/#:~:text=The%20plan%20sets%20a%20target%20of%2020%25%20non%2Dfossil%20energy,18%25%20from%202020%20to%202025.

Pauleit, Stephan, Teresa Zölch, Rieke Hansen, Thomas B. Randrup, and Cecil Konijnendijk van den Bosch. 2017. "Nature-Based Solutions and Climate Change – Four Shades of Green." *Nature-Based Solutions to Climate Change Adaptation in Urban Areas* 29-49.

Ritchie, Hanna. 2020. *Sector by sector: where do global greenhouse gas emissions come from?* September 18. Accessed February 17, 2021. https://ourworldindata.org/ghg-emissions-by-sector.

Ritchie, Hannah, and Max Roser. 2020. *CO_2 and Greenhouse Gas Emissions.* Accessed February 16, 2021. https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions.

Song, Jian, Shiqiang Wan, Shushi Peng, Shilong Piao, Phillippe Ciais, Xingguo Han, De-Hui Zeng, et al. 2021. "The carbon sequestration potential of China's grasslands." *Ecosphere* pp.e02452.

Tang, Xuli, Xia Zhao, and Yongfei Bai. 2018. "Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey." *PNAS* 115 (16): https://doi.org/10.1073/pnas.1700291115.

Tao, Fulu, Taru Palosuo, and Raisa Makipaa. 2019. "Cropland soils in China have a large potential for carbon sequestration based on literature survey." *Soil and Tillage Research* 70-78.

Tian, Hanqin, Jerry Melillo, Chaoqun Lu, David Kicklighter, Mingliang Liu, Wei Ren, Xiafeng Xu, et al. 2011. "China's terrestrial carbon balance: Contributions from multiple global change factors." *Global Biogeochemical Cycles* https://doi.org/10.1029/2010GB003838.

UNEP. 2021. *Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered.* Nairobi: United Nations Environment Programme.

Viña, Andrés, Willliam J. McConnell, Hongbo Yang, Zhenci Xu, and Jianguo Liu. 2016. "Effects of conservation policy on China's forest recovery." *Ecosystems* e150096.

Wang, Hui, Mengyu He, Nan Ran, Dong Xie, Qiang Wang, Mingjun Teng, and Pengcheng Wang. 2021. "China's Key Forestry Ecological Development Programs: Implementation, Environmental Impact and Challenges." *Forests.*

Wang, Li-Xia, Ji-Xi Gao, Wen-Ming Shen, Yuan-Li Shi, and Hong-Wei Zhang. 2020. "Carbon storage in vegetation and soil in Chinese ecosystems estimatead by carbon transfer rate method." *Ecosphere* 1-11.

Wang, Yicheng, Fulu Tao, Yi Chen, and Lichang Yin. 2022. "Interactive impacts of climate change and agricultural management on soil organic carbon sequestration potential of cropland in China over the coming decades." *Science of the Total Environment* 153018.

Watson, Robert T., Ian R. Noble, Bert Bolin, N. H. Ravindranath, David J. Verardo, and David J. Dokken. 2000. *Land Use, Land-Use Change and Forestry.* Accessed February 18, 2022. https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=3.

Weki, Da, and Xiaodan Wang. 2017. "Uncertainty and dynamics of natural wetland CH4 release in China: Research status and priorities." *Atmospheric Environment* 95-105.

Xiao, Derong, Lei Deng, Dong-Gill Kim, Chunbo Huang, and Kun Tian. 2018. "Carbon budgets of wetland ecosystems in China." *Global Change Biology* 2061-2075.

Xiaonan, Duan, Wang Xiake, Fei Lu, and Ouyang Zhiyun. 2008. "Primary evaluation of carbon sequestration potential of wetlands in China." *Acta Ecologica Sinica* 463-469.

Xie, Wei, Jikun Huang, Jinxia Wang, Qi Cui, Ricky Robertson, and Kevin Chen. 2020. "Climate change impacts on China's agriculture: The responses from market and trade." *China Economic Review* (China Economic Review).

Xie, Zubin, Jianguo Zhu, Gang Liu, Georg Cadisch, Toshihiro Hasegawa, Chunmei Chen, Huifeng Sun, Haoyan Tang, and Qing Zeng. 2007. "Soil organic carbon stocks in China and changes from 1980s to 2000s." *Global Change Biology* 1989–2007.

Xu, Jintao, Runsheng Yin, Zhou Li, and Can Liu. 2006. "China's ecological rehabilitation: Unprecedented efforts, dramatic impacts, and requisite policies." *Ecological Economics* 595-607.

Xu, Li, Guirui Yu, and Nianpeng He. 2019. "Increased soil organic carbon storage in Chinese terrestrial ecosystems from the 1980s to the 2010s ." *Journal of Geographic Sciences* 49-66.

Yang, Haijiang, Gou Xiahua, and Dingcai Yin. 2021. "Response of Biodiversity, Ecosystems, and Ecosystem Services." *Ecologies.*

Zhai, Deli, Jianchu Xu, Zhicong Dai, and Dietrich Schmidt-Vogt. 2017. "Lost in transition: Forest transition and natural forest loss in tropical China." *Plant Diversity* 149-153.

Zhang, Shu, and Wenying Chen. 2021. "China's energy transition pathway in a carbon neutral vision." *Engineering* doi: https://doil.org/10.1016/j.eng.2021.09.004.

Zhang, Yu, Ji Yuan, Chengming You, Rui Cao, Bo Tan, and Wanqin Yang. 2020. "Contributions of National Key Forestry Ecology Projects to the forest vegetation carbon storage in China." *Forest Ecology and Management* 117981.

Zheng, YaoMin, ZhenGuo Niu, Peng Gong, YongJiu Dai, and Wei Shangguan. 2013. "Preliminary estimation of the organic carbon pool in China's wetlands." *Chinese Science Bulletin* 662-670.

Annex

Biome	Included Studies
Forests	Piao, S. et al. Changes in vegetation net primary productivity from 1982 to 1999 in China. Global Biogeochem. Cycles 19, GB2027 (2005) Ni, J. Carbon storage in terrestrial ecosystems of China: estimates at diferent spatial resolutions and their responses to climate change. Clim. Change 49, 339–358 (2001). Liu, G. H., Fu, B. J. & Fang, J. Y. Carbon dynamics of Chinese forests and its contribution to global carbon balance. Acta Ecol. Sin. 20, 733–740 (2000). Zhou, Y. R., Yu, Z. L. & Zhao, S. D. Carbon storage and budget of major Chinese forest types. Chin. J. Ecol. 24, 518–522 (2000). Pan, Y., Luo, T., Birdsey, R., Hom, J. & Melillo, J. New estimates of carbon storage and sequestration in China's forests: effects of age class and method on inventory-based carbon estimation. Clim. Change 67, 211–236 (2004). Zhao, M. & Zhou, G. Carbon storage of forest vegetation and its relationship with climatic factors. Scientia Geogr. Sin. 24, 50–54 (2004). Li, K. R., S. Q. Wang, and M. K. Cao. 2003. Vegetation and soil carbon storage in China. Science in China Series D Earth Sciences 47:49–57 Fang, J., Chen, A., Peng, C., Zhao, S. & Ci, L. Changes in forest biomass carbon storage in China between 1949 and 1998. Science 292, 2320–2322 (2001). Fang JY, Guo ZD, Piao SL, Chen AP (2007) Terrestrial vegetation carbon sinks in China, 1981-2000. Sci China Ser D-Earth Sci 50:1341-1350; Fang JY, et al. (2001) Changes in forest biomass carbon storage in China between 1949-1998. Science 292:2320-2322 Fang, J., Guo, Z., Piao, S. & Chen, A. Terrestrial vegetation carbon sinks in China, 1981–2000. Sci. China D. 50, 1341–1350 (2007). Xu, X. L., Cao, M. K. & Li, K. R. Temporal-Spatial dynamics of carbon storage of forest vegetation in China. Progress Geogr. 26, 1–10 (2007) Wu, Q. B. et al. Carbon sequestration and its potential by forest ecosystems in China. Acta Ecol. Sin. 28, 517–524 (2008). Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Li, H. K., Lei, Y. C. & Zeng, W. S. Forest carbon storage in China estimated using forestry inventory data. Scientia Silvae Sinicae 47, 7–12 (2011). Zhang, C. et al. China's forest biomass carbon sink based on seven inventories from 1973 to 2008. Clim. Change 118, 933–948 (2013). Zhao, M., Yue, T., Zhao, N., Sun, X. & Zhang, X. Combining LPJ-GUESS and HASM to simulate the spatial distribution of forest vegetation carbon stock in China. J. Geogr. Sci. 24, 249–268 (2014). Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Fang JY, et al. (2014) Evidence for environmentally enhanced forest growth. Proc Natl Acad Sci USA 111:9527-9532 Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341. Tang, et al. (2018). Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey. PNAS, 115(16) Xie, X. L., Sun, B., Zhou, H. Z. & Li, Z. P. Soil carbon stocks and their infuencing factors under native vegetations in China. Acta Pedologica Sin 41, 687–699 (2004). Xie, Z. B. et al. Soil organic carbon stocks in China and changes from 1980s to 2000s. Global Change Biol. 13, 1989–2007 (2007). Yang, Y. H., Mohammat, A., Feng, J. M., Zhou, R. & Fang, J. Y. Storage, patterns and environmental controls of soil organic carbon in China. Biogeochemistry 84, 131–141 (2007).

	Xu, L. et al. Differences in pedotransfer functions of bulk density lead to high uncertainty in soil organic carbon estimation at regional scales: Evidence from Chinese terrestrial ecosystems. J Geophys. Res: Biogeosciences 120, 1567–1575 (2015). Fang, J., Chen, A., Peng, C., Zhao, S., and Ci, L. (2001b). Changes in forest biomass carbon storage in China between 1949 and 1998. Science 292, 2320–2322. Dixon, R. K., S. Brown, R. A. Houghton, A. M. Solo-mon, M. C. Trexler, and J. Wisniewski. 1994. Car-bon paools and flux of global forest ecosystem.Science 26414:185–190 Zhou, Y. R., Yu, Z. L. & Zhao, S. D. Carbon storage and budget of major Chinese forest types. Chin. J. Ecol. 24, 518–522 (2000). Li, K. R., S. Q. Wang, and M. K. Cao. 2003. Vegetation and soil carbon storage in China. Science in ChinaSeries D Earth Sciences 47:49–57 Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Tang, et al. (2018). Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey. PNAS, 115(16)
Grasslands	Zhang, L., Zhou, G.S., Ji, Y.H., and Bai, Y.F. (2016). Spatiotemporal dynamic simulation of grassland carbon storage in China. Sci China Earth Sci 59, 1946–1958 Fang JY, Liu GH, Xu SL (1996a) Biomass and net production of forest vegetation in China. Acta Ecologica Sinica 16:497-508. Li, K., Wang, S. & Cao, M. Vegetation and soil carbon storage in China. Sci. China 47, 49–57 (2004). Ni, J. Carbon storage in grasslands of China. J. Arid Environ. 50, 205–218 (2002) Piao, S., Fang, J., Zhou, L., Tan, K. & Tao, S. Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. Global Biogeochem. Cycles 21, GB2002 (2007). Fang, J., Yang, Y., Ma, W., Mohammat, A. & Shen, H. Ecosystem carbon stocks and their changes in China's grasslands. Sci. China 53, 757–765 (2010) Piao, S. L., Fang, J. Y., He, J. S. & Xiao, Y. Spatial distribution of grassland biomass in China. Chin. J. Ecol. 28(4), 491–498 (2004) Piao SL, et al. (2007) Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. Global Biogeochem Cy 21: GB2002. Ni, J. Carbon storage in terrestrial ecosystems of China: estimates at diferent spatial resolutions and their responses to climate change. Clim. Change 49, 339–358 (2001). Fang, J., Guo, Z., Piao, S. & Chen, A. Terrestrial vegetation carbon sinks in China, 1981–2000. Sci. China D. 50, 1341–1350 (2007). Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Fan, J. W. et al. Carbon storage in the grasslands of China based on field measurements of above- and below-ground biomass. Clim. Change 86, 375–396 (2008). Ma, A., He, N., Yu, G., Wen, D. & Peng, S. Carbon storage in Chinese grassland ecosystems: Influence of different integrative methods. Sci. Rep. 6, srep21378 (2016). Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341. Xie, X. L., Sun, B., Zhou, H. Z. & Li, Z. P. Soil carbon stocks and their influencing factors under native vegetations in China. Acta Pedologica Sin 41, 687–699 (2004). Xie, Z. B. et al. Soil organic carbon stocks in China and changes from 1980s to 2000s. Global Change Biol. 13, 1989–2007 (2007).

	Yang, Y. H., Mohammat, A., Feng, J. M., Zhou, R. & Fang, J. Y. Storage, patterns and environmental controls of soil organic carbon in China. Biogeochemistry 84, 131–141 (2007) Xu, L. et al. Diferences in pedotransfer functions of bulk density lead to high uncertainty in soil organic carbon estimation at regional scales: Evidence from Chinese terrestrial ecosystems. J Geophys. Res: Biogeosciences 120, 1567–1575 (2015). Xu, L., Yu, G., and He, N. (2019). Increased soil organic carbon storage in Chinese terrestrial ecosystems from the 1980s to the 2010s. J Geogr Sci 29, 49–66. Ni, J. Carbon storage in grasslands of China. J. Arid Environ. 50, 205–218 (2002) Fang, J., Yang, Y., Ma, W., Mohammat, A. & Shen, H. Ecosystem carbon stocks and their changes in China's grasslands. Sci. China 53, 757–765 (2010) Li, K., Wang, S. & Cao, M. Vegetation and soil carbon storage in China. Sci. China 47, 49–57 (2004). Ni, J. Carbon storage in terrestrial ecosystems of China: estimates at different spatial resolutions and their responses to climate change. Clim. Change 49, 339–358 (2001). Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Ma, A., He, N., Yu, G., Wen, D. & Peng, S. Carbon storage in Chinese grassland ecosystems: Influence of different integrative methods. Sci. Rep. 6, srep21378 (2016). Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341.
Cropland	Li, K., Wang, S. & Cao, M. Vegetation and soil carbon storage in China. Sci. China 47, 49–57 (2004). Fang, et al. (2007). Terrestrial vegetation carbon sinks in China, 1981-2000. 50(9):1341-1350 Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341. Tang, et al. (2018). Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey. PNAS, 115(16) Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Lu, F., et. (2018). Effect of national ecological restoration projects on carbon sequestration in China from 2001 to 2010 Fang, et al. (2018). Climate change, human impacts, and carbon sequestration in China Xie, Z. B. et al. Soil organic carbon stocks in China and changes from 1980s to 2000s. Global Change Biol. 13, 1989–2007 (2007). Yang, Y. H., Mohammat, A., Feng, J. M., Zhou, R. & Fang, J. Y. Storage, patterns and environmental controls of soil organic carbon in China.Biogeochemistry 84, 131–141 (2007) Xu, L. et al. Diferences in pedotransfer functions of bulk density lead to high uncertainty in soil organic carbon estimation atregional scales: Evidence from Chinese terrestrial ecosystems. J Geophys. Res: Biogeosciences 120, 1567–1575 (2015). Yu DS, et al. (2007) Regional patterns of soil organic carbon stocks in China. J Environ Manage 85:680-689 Zhang, F., Wang, Z., Glidden, S., Wu, Y.P., Tang, L., Liu, Q.Y., Li, C.S., and Frolking, S. (2017). Changes in the soil organic carbon balance on China's cropland during the last two decades of the 20th century. Sci Rep 7, 7144 Li, K., Wang, S. & Cao, M. Vegetation and soil carbon storage in China. Sci. China 47, 49–57 (2004). Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109.

	Tang, H., Qiu, J., Wang, L., Li, H., Li, C., and van Ranst, E. (2010). Modeling soil organic carbon storage and its dynamics in croplands of China. Agric Sci China 9, 704–712. Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Fang, et al. (2018). Climate change, human impacts, and carbon sequestration in China Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341.
Wetland	Xiao, D., Deng, L., Kim, D.G., Huang, C., and Tian, K. (2019). Carbon budgets of wetland ecosystems in China. Glob Change Biol 25, 2061– 2076 Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Xu, L. et al. Diferences in pedotransfer functions of bulk density lead to high uncertainty in soil organic carbon estimation at regional scales: Evidence from Chinese terrestrial ecosystems. J Geophys. Res: Biogeosciences 120, 1567–1575 (2015). Yu DS, et al. (2007) Regional patterns of soil organic carbon stocks in China. J Environ Manage 85:680-689 Xu, L., Yu, G., and He, N. (2019). Increased soil organic carbon storage in Chinese terrestrial ecosystems from the 1980s to the 2010s. J Geogr Sci 29, 49–66. Lu, M., Zou, Y., Xun, Q., Yu, Z., Jiang, M., Sheng, L., Lu, X., and Wang, D. (2021). Anthropogenic disturbances caused declines in the wetland area and carbon pool in China during the last four decades. Glob Change Biol 27, 3837–3845. Xiao, D., Deng, L., Kim, D.G., Huang, C., and Tian, K. (2019). Carbon budgets of wetland ecosystems in China. Glob Change Biol 25, 2061– 2076 Niu, Z.G., Gong, P., Cheng, X., Guo, J.H., Wang, L., Huang, H.B., Shen, S. Q., Wu, Y.Z., Wang, X.F., Wang, X.W., et al. (2009). Geographical characteristics of China's wetlands derived from remotely sensed data. Sci China Ser D 52, 723–738. Zhang, X.H., Li, D.Y., Pan, G.X., Li, L.Q., Lin, F., and Xu, X.W. (2008). Conservation of wetland soil carbon stock and climate change of China (in Chinese). Adv Clim Change Res 4, 202–208. Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Xiao, D., Deng, L., Kim, D.G., Huang, C., and Tian, K. (2019). Carbon budgets of wetland ecosystems in China. Glob Change Biol 25, 2061– 2076 Zheng, Y., et al. (2013). Preliminary estimation of the organic carbon pool in China's wetland. Chinese Science Bulletin
Shrubland	Hu, H. F., Wang, Z. H., Liu, G. H. & Fu, B. J. Vegetation carbon storage of major shrublands in China. Chin. J. Ecol. 30, 539–544 (2006) Fang JY, Liu GH, Xu SL (1996) Soil carbon pool in China and its global significance. J Environ Sci 8: 249-254. Li, K., Wang, S. & Cao, M. Vegetation and soil carbon storage in China. Sci. China 47, 49–57 (2004). Ni, J. Carbon storage in terrestrial ecosystems of China: estimates at diferent spatial resolutions and their responses to climate change. Clim. Change 49, 339–358 (2001). Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Zhang, C. et al. China's forest biomass carbon sink based on seven inventories from 1973 to 2008. Clim. Change 118, 933–948 (2013). Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341. Tang, et al. (2018). Carbon pools in China's terrestrial ecosystems: New estimates based on an intensive field survey. PNAS, 115(16) Xie, X. L., Sun, B., Zhou, H. Z. & Li, Z. P. Soil carbon stocks and their infuencing factors under native vegetations in China. Acta Pedologica Sin 41, 687–699 (2004).

	Li, K., Wang, S. & Cao, M. Vegetation and soil carbon storage in China. Sci. China 47, 49–57 (2004). Ni, J. Carbon storage in terrestrial ecosystems of China: estimates at diferent spatial resolutions and their responses to climate change. Clim. Change 49, 339–358 (2001). Xu, L. et al. Carbon storage in China's terrestrial ecosystems: A synthesis. Scientific Reports, (2018) Yu GR, et al. (2010) Carbon storage and its spatial pattern of terrestrial Ecosystem in China. Journal of Resource and Ecology 1: 97-109. Wang, L.X., Gao, J.X., Shen, W.M., Shi, Y.L., and Zhang, H.W. (2021a). Carbon storage in vegetation and soil in Chinese ecosystems estimated by carbon transfer rate method. Ecosphere 12, e03341. Tang, et al. (2018). Carbon pools in China’s terrestrial ecosystems: New estimates based on an intensive field survey. PNAS, 115(16)