processes

Article

Carbon Accounting of Weihe CSA Pilot Demonstration Area in Longjiang Forest Industry

Kexin Ma [1,†], Meiyun Geng [1,†], Lidong Han [2], Qingfang Sun [3], Leihao Zhang [1], Zekai Yang [1], Yue Tang [1], Sihan Guo [1], Yufei Xiao [2], Di Zhang [2] and Xiaotang Wo [2,*]

[1] Horticultyre College, Northeast Agricultural University, Harbin 150030, China
[2] Carbon Sink Center, Heilongjiang Ecology Institute, Harbin 150081, China
[3] School of Geography and Tourism, Harbin University, Harbin 150081, China
* Correspondence: woxt200206@163.com
† These authors contributed equally to this work.

Abstract: Carbon sink afforestation (CSA) has become one of the most concerned issues of countries around the world under the background of climate change. The northern forest ecosystem, located in mid- and high latitudes, is a huge terrestrial carbon pool and is very sensitive to climate change. Studying the carbon emission accounting of CSA in northern forests helps clarify the contribution of CSA to forestry carbon sequestration and forecasts the carbon sink effect of forest ecosystems. It is of great significance for the assessment of forest carbon sink and carbon cycling by providing a scientific basis and reference for the development, utilization, and management of carbon sink afforestation, as well as the coordinated development of ecology and social economy. At present, research on the carbon emission accounting of the CSA in northern China is still lacking. According to the relevant models and parameters of estimating live biomasses with the default method from *the IPCC's* (Intergovernmental Panel on Climate Change) *Technical Guidelines for National Forestry Carbon Sink Accounting and Monitoring*, carbon stock, carbon emission, and carbon leakage of the Weihe CSA (carbon sink afforestation) pilot demonstration area in the boreal Longjiang Forest Industry in a baseline scenario and CSA scenario were measured, and the CSA's net carbon sink was estimated. The conclusions were as follows: (1) By the end of the crediting period of the project's baseline, carbon fixation reached 101.85 t CO_2, with an average annual CO_2 fixation of 5.09 t. By the end of the CSA term, carbon sequestration was accumulated as 382.13 t CO_2, with an average annual sequestration of 19.11 t CO_2, nearly four times that of the baseline period. (2) By the end of the CSA term, the carbon sequestration of the coniferous standing forest was 46.2% higher than that of the broad-leaved standing forest, accounting for 65% of the total carbon sequestration of the forest. The carbon sequestration of the tree species in the coniferous forest in descending order is *Picea koraiensis*, *Pinus koraiensis*, *Larix olgensis*, *Fraxinus mandshurica*, and *Populus cathayana*. The carbon sink density of the coniferous standing forest was 8.7% higher than that of the broad-leaved standing forest. (3) The carbon fixation of the coniferous standing forest nearly doubled that of the broad-leaved standing forest. The highest carbon fixation belongs to *Fraxinus mandshurica*, closely followed by *Picea koraiensis* and *Pinus koraiensis* at a high level, and then *Larix olgensis* and *Populus cathayana*. The carbon fixation of *Fraxinus mandshurica* was 20 times that of *Populus cathayana*. (4) The accumulated greenhouse gas emissions within the boundary during the CSA period were 2.53 t CO_2-e. The accumulated greenhouse gas leakage outside the boundary was 0.05 t CO_2-e. Carbon emissions occurred in the first, second, and third years of the crediting period, while carbon leakage occurred only in the first year. (5) This result appeared as carbon sources during the first three years of the CSA period but changed to carbon sink from the fourth year and then accumulated to 280.28 t (70.07 t $CO_2\text{-e}\cdot\text{hm}^{-2}$) as a net carbon sink by the end of the term. The Weihe CSA appeared to have a relatively strong ability of carbon sequestration in temperate forests. The CSA activity is influenced by factors such as policies, environment, management, etc., resulting in uncertainties in carbon sequestration accounting. Therefore, it is suggested that comparison studies and investigations should be strengthened, and multiple methods should be integrated into carbon sequestration estimation and accounting, leading the carbon accounting of forest ecosystems to a high-level and comprehensive development.

Citation: Ma, K.; Geng, M.; Han, L.; Sun, Q.; Zhang, L.; Yang, Z.; Tang, Y.; Guo, S.; Xiao, Y.; Zhang, D.; et al. Carbon Accounting of Weihe CSA Pilot Demonstration Area in Longjiang Forest Industry. *Processes* **2023**, *11*, 1251. https://doi.org/10.3390/pr11041251

Academic Editors: Yongqing Xu, Bowen Lu, Yuchuan Feng and Xing Yuan

Received: 22 February 2023
Revised: 6 April 2023
Accepted: 12 April 2023
Published: 18 April 2023

Keywords: forest industry; carbon accounting; carbon sink afforestation; demonstration area

1. Introduction

The IPCC (Intergovernmental Panel on Climate Change)'s Fifth Assessment Report points out that in the past century, human activities such as fossil fuel combustion, land use change, deforestation, and reclamation have led to increased concentrations of greenhouse gases in the atmosphere, such as CO_2, leading to global warming [1,2]. Forests, as a huge carbon pool and carbon sink, bring forestry an important role in achieving the goal of "carbon peaking and carbon neutrality" and carry the hope of human beings to reduce atmospheric CO_2 and slow down global warming. Developing a forestry carbon sink will help forestry play its role to the greatest extent and make the status of forestry [3–5] prominent. A forestry carbon sink is an important part of the national climate change strategy and a significant field of national ecological construction [6–10]. It is also a critical basis for assessing the value of forest ecological protection and ecological services [11–14]. The calculation and examination of forestry carbon sinks have become a focus of international climate change and negotiations, and it is of great significance to accurately estimate the net carbon sink of CSA (carbon sink afforestation) [15–19].

In recent years, scholars have carried out lots of research on the calculation and assessment of forestry carbon sequestration with mainly mathematical and statistical methods, focusing on forestry carbon sequestration and the value and effects of carbon sink in different regions, as well as its impact on ecosystems, the economy, society, and the environment, and suggestions on pathways to increase carbon sequestration [20–22]. Carbon sequestration methodology is the estimating guidance of carbon sequestration and greenhouse gas emission changes in the process of forestry carbon sink activities. As an important basis for carbon accounting, it provides some foundations for the scientific measurement, monitoring, and management of forestry carbon sequestration. At present, research on forestry carbon sequestration accounting with carbon sequestration methodology is carried out mostly in forests in low-latitude regions, such as tropical and subtropical regions, while it is relatively scarce in higher-latitude forest regions in the north [23–25].

China's state-owned forest areas are a crucial basis for the development of a forestry carbon sink, and the forestry carbon sink of these areas is an important mission for forestry in the new era. The state-owned forest area of the Longjiang Forest Industry is the largest key forest area in China, and its rich forest resources play a vital role in regulating the regional ecological balance and slowing down the greenhouse effect [26,27]. With increasing attention to forest carbon sinks and the development of carbon sink forestry, scientific research on carbon sequestration in the forest industrial areas of Heilongjiang Province has started. Accounting and monitoring of carbon sink forestry in forest areas can help provide a scientific evaluation system of reasonably assessing the potential advantages of these forest areas, and it is critical for forestry carbon sink activities to be fully involved in the national response to climate change [28,29]. Furthermore, it will provide data support and a calculation platform to participate in the carbon sink trade for the forest industry areas in Heilongjiang Province [30,31]. Based on this, according to relevant models and parameters of estimating live biomasses with the default method from the *IPCC's Technical Guidelines for National Forestry Carbon Sink Accounting and Monitoring*, the baseline scenario of the IPCC's CSA pilot demonstration area of carbon sink afforestation in the Longjiang Forest Industry was assessed, and the CSA's carbon stock, carbon emission, and carbon leakage were measured. The CSA's net carbon sink was also estimated. The results provided a reference for building the ecological environment of the Longjiang Forest Industry and formulating countermeasures for regional forest ecosystem carbon sink management against the background of global climate change.

2. Materials and Methods

2.1. Overview of the Study Area

Located at the western foot of Zhangguangcai Mountain in the Changbai Mountain range, the Weihe Forestry Bureau of Heilongjiang Province was recognized as a pilot demonstration area of the natural forest resources protection project in 1998. The Weihe Forestry area belongs to the Changbai Mountain flora area, and it is one of the distribution areas of the broad-leaved forests of northeast *Pinus koraiensis*. The area has rich plant resources, with the dominant tree species, including *Pinus koraiensis, Picea koraiensis*, *Abies fabri* (Mast.) Craib, *Fraxinus mandshurica*, and *Jiglant mandshurica*, distributed in the mixed broadleaf–conifer forest at an altitude of 300–1200 m. Weihe Forestry is located in the middle temperate zone with a humid monsoon climate and an annual average temperature of 22 °C. The uttermost lowest temperature is -41 °C, and the frost period and the frostless period usually fall from October to April. The annual precipitation is 680–730 mm, and most precipitation is in June, July, and August (accounting for 65.2% of the annual precipitation).

In this study, Sub-Compartment 1 of Compartment 74 of the Xinxing Forest Area of the Weihe Forestry Bureau was selected as the CSA demonstration area, whose geographical location coordinates were $128^\circ 28' 04.58''$ E and $45^\circ 02' 45.70''$ N. Sub-Compartment 1 covered an area of 4 hectares, with an average altitude of 276.9 m and a southward slope at an incline of 21 degrees. In the demonstration area, there were 915 Picea koraiensis (a kind of arbor) of a seedling age of 13 (years) and a forest stand area of 0.605 hectares. Shrubs and herbs were unevenly distributed, and the land belonged to barren hills and wasteland.

2.2. Research Methods

The research work consisted of two parts: Firstly, in May 2018, we determined the carbon pool through a baseline carbon pool survey and the stratification of CSA in the study area (Class 1, Xinxing Forest Farm 74, Heilongjiang Weihe Forestry Bureau), and we conducted field investigations and experiments, such as planting and maintenance of the CSA, according to the afforestation plan (the tree species configuration method and seedling specifications); then, according to the relevant models and parameters of the "National Technical Guidelines for Forest Carbon Sequestration Calculating and Monitoring" from the IPCC, we carried out the baseline scenario (no afforestation yet) and simulated an estimation and assessment towards carbon sequestration, carbon emission, and carbon leakage in the study area during the crediting period of the CSA (the future 20 years), and finally, we calculated and estimated the net carbon sequestration of the afforestation project.

2.2.1. Baseline Survey and Stratification

In the same unit, afforestation plots that were basically the same were taken as the same category to be stratified. Based on this survey principle, the baseline plots were divided into three layers, as shown in Table 1. Vegetation coverage of each layer at the baseline was as follows: shrubs and herbs at the BSL-1 layer; zero vegetation coverage at the BSL-2 layer; Picea koraiensis and herbs at the BSL-3 layer, in which the DBH of each Picea koraiensis was determined, and the planting area and the forest stand age were investigated. Three evenly distributed 5 m × 5 m shrub samples in the shrub-covered area were selected and were set in an equilateral triangular shape to directly determine the shrub biomass with the harvest method. The investigation method for the herb-covered area was the same as that for the shrub-covered area. A baseline stratification plane graph was completed according to boundary data and topographic map data (Figure 1).

2.2.2. Carbon Pool Selection and Determination

According to the carbon pool estimation method from the *IPCC's Technical Guidelines for National Forestry Carbon Sink Accounting and Monitoring*, the overall carbon stock was the sum of each carbon stock component (carbon above the ground, carbon below the ground, litter, dead trees and grass, and the soil's carbon). To calculate the baseline carbon stock change, it was conservatively assumed that the three carbon pools of the soil's organic carbon, litter, and dead trees and grass were in a stable or degraded state, with no change of carbon stock, and only the carbon stock change in the above-ground biomass and below-ground biomass was considered [32,33].

Table 1. Baseline stratification.

Carbon Layer Number	Scattered Trees			Shrubs		Herbs	
	Dominant Tree Species	Average Age/a	Quantity/Plants	Average Coverage /%	Average Height/cm	Average Coverage /%	Average Height/cm
BSL-1	Non	0	0	10	50	30	25
BSL-2	Non	0	0	0	0	0	0
BSL-3	*Picea koraiensis*	13	915	0	0	10	25

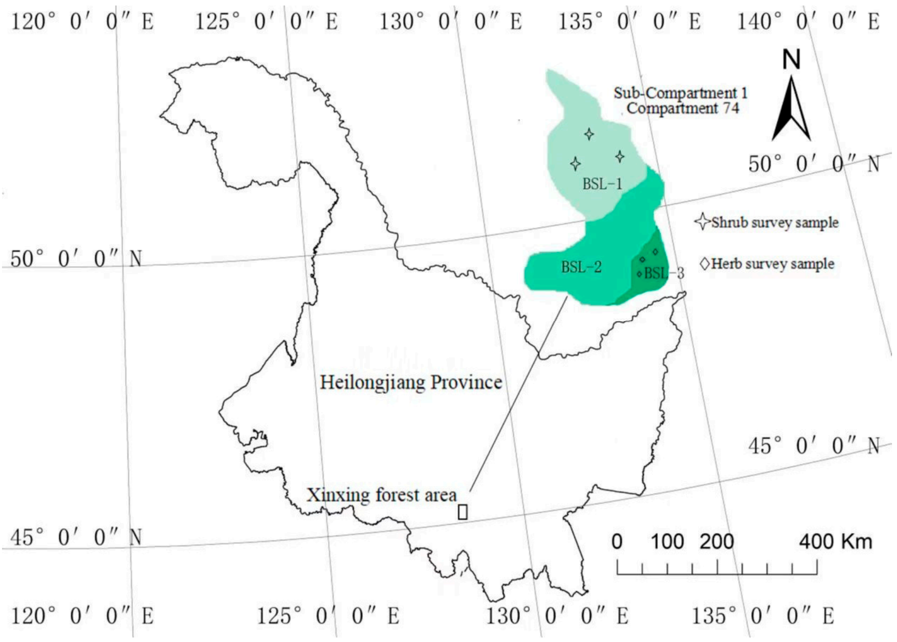

Figure 1. Baseline stratification scheme.

2.2.3. CSA Design

According to the general principles of the *Technical Regulation for Afforestation for Carbon Sequestration*, in the afforestation plan, 5 native tree species with strong vitality, complete roots, and no diseases or insect pests were finally identified, including *Pinus koraiensis*, *Picea koraiensis*, *Larix olgensis*, *Fraxinus mandshurica*, and *Populus cathayana*. Afforestation density: 3300 plants/hectare; tree species configuration: mixed by strips along the slope direction; spacing in the rows and spacing between rows: 2 m × 1.5 m; mixed species proportion of *Pinus koraiensis*, *Picea koraiensis*, and *Fraxinus mandshurica*: 1:1:1; mixed species proportion of *Larix olgensis* and *Populus cathayana*: 4:1. The detailed seedling specifications are shown in Table 2:

Table 2. Statistics of afforestation tree species.

Tree Species	Seedling Age Type	Seedling Height/cm	Quantity /Plants	Proportion /%	Area /hm^2
Pinus koraiensis	S2-2	>30	3075	25.84	1.034
Picea koraiensis	S2-2	>30	3475	29.20	1.168
Larix olgensis	S1-1	>50	933	7.84	0.314
Fraxinus mandshurica	S2-0	>50	4217	33.14	1.417
Populus cathayana	C3-2	>50	200	1.68	0.067
Total			11,900	100	4

Note: The first number of the seedling age indicates the age of seeding plants or planting stock in situ, and the second number indicates the cultivation years after the first transplanting.

$$C_{TREE,j,t} = \sum \left(B_{TREE,j,t} \times CF_{TREE,j}\right) \tag{1}$$

$$B_{TREE,j,t} = B_{TREE,j,t-1} + A \times (1 + R) \times G_{TREE,j,t} \tag{2}$$

Table 3. Relevant parameters of the forest stand's carbon stock calculation model.

Tree Species	Carbon Content /t C·(t d.m.)$^{-1}$	Ratio of Root to Stem	Forest Stand Area /hm^2	Average Annual Increment of Partial Above-Ground Biomass /(t d.m.)·hm^{-2}·a^{-1}	
				≤20 Age Class	>20 Age Class
Pinus koraiensis	0.51	0.40	1.034	1.5	2.5
Picea koraiensis	0.51	0.40	1.168	1.5	2.5
Larix olgensis	0.51	0.40	0.314	1.5	2.5
Fraxinus mandshurica	0.48	0.46	1.417	1.5	1.5
Populus cathayana	0.48	0.46	0.067	1.5	5

Note: the G_w value refers to the annual average increment of partial above-ground biomass in the boreal forests of Asia from the *IPCC's Technical Guidelines for National Forestry Carbon Sink Accounting and Monitoring*. Units in the table: "t": ton; "C":;carbon; "d.m.": biomass; "hm^2": hectare; "a": year.

In the formula:

$C_{TREE,j,t}$	In year *t*, the forest biomass carbon storage of tree species j (t C);
$B_{TREE,j,t}$	In year *t*, the biomass of tree species j (t d.m.);
$CF_{TREE,j}$	The carbon content rate of the biomass of tree species j [t C·(t d.m.) $^{-1}$];
$B_{TREE,j,t-1}$	In year *t* −1, the biomass of tree species j (t d.m.);
A	Stand area hectares (hm^2);
R	Root stem ratio;
$G_{TREE,j,t}$	In year *t*, the annual average increment of aboveground biomass per unit area of tree species j [(t d.m.)·hm^{-2}· a^{-1}];
t	1–20, the number of years since the beginning of afforestation (a).

$$C_{SHRUB,t} = B_{SHRUB} \times A_{,t} \times CF_{SHRUB} \tag{3}$$

In the formula:

$C_{SHRUB,t}$	In year *t*, carbon storage of shrub and herb biomass (t C);
B_{SHRUB}	Biomass per unit area of shrubs and herbs (t d.m.);
$A_{,t}$	n year *t*, the area of shrubs and herbs (hm^2);
CF_{SHRUB}	Carbon content rate of shrubs and herbs [t C·(t d.m.)$^{-1}$];
t	1–20, the number of year since the beginning of afforestation (a).

$$EN\_Fertilizer, t = [(FSN, t + FON, t) \times EF1] \times MWN2O \times GWPN2O \tag{4}$$

$$F_{SN,t} = \sum M_{SFi,t} \times NC_{SFi} \times (1 - Frac_{GASF}) \tag{5}$$

$$F_{ON,t} = \sum M_{OFj,t} \times NC_{OFj} \times (1 - Frac_{GASM}) \tag{6}$$

In the formula:

$E_{N\_Fertilizer,t}$	In year t, the increase in NO_2 emissions caused by the application of nitrogen fertilizers within the project boundary (t CO_2-e·a^{-1});
$F_{SN,t}$	In year t, the amount of nitrogen fertilizer applied after volatilization of NH_3 and NO_X (t N·a^{-1});
$F_{ON,t}$	In year t, the amount of organic fertilizer applied after volatilization of NH_3 and NO_X (t N·a^{-1});
EF_1	N_2O as the emission factor from nitrogen fertilizer application, 0.01 as the reference from IPCC (t N_2O-N);
MW_{N2O}	Molecular weight ratio of N_2O to N (44/28);
GWP_{N2O}	Global warming trend of N_2O, 310 as the reference from IPCC [t CO_2-e·(t $N_2O)^{-1}$];
$M_{SFi,t}$	In year t, the amount of i -type fertilizer applied (t·a^{-1});
$M_{OFj,t}$	In year t, the amount of j -type organic fertilizer applied (t·a^{-1});
NC_{SFi}	The nitrogen content of i -type fertilizer [g N·(100 g fertilizer$)^{-1}$)];
NC_{OFj}	The nitrogen content of j -type organic fertilizer [g N (100 g organic fertilizer$)^{-1}$)];
$Frac_{GASF}$	The volatilization ratio of NH_3 and NO_X in fertilizer application, 0.1 as the reference from IPCC;
$Frac_{GASM}$	The volatilization ratio of NH_3 and NO_X in organic fertilizer application, 0.2 as the reference from IPCC;
t	1–20, the number of years since the beginning of afforestation (a);
i	Fertilizer type, i = 1, . . . ,I;
j	Organic fertilizer type, j = 1, . . . ,J.

$$LKvehicler, t = \sum (EFCO2, f) \tag{7}$$

In the formula:

$LK_{vehicler,t}$	In year t, CO_2 emissions caused by transportation outside the project boundary(t CO_2-e · a^{-1});
$EF_{CO2,f}$	CO_2 as the emission factor from f-type fuel(t CO_2-e·GJ^{-1});
NCV_f	The calorific value of f-type fuel (GJ·L^{-1});
$FC_{f,t}$	In year t, the consumption of f-type fuel (L);
t	1–20, the number of years since the beginning of afforestation (a);
f	Fuel type, f = 1, . . . ,F.

$$E_{,t} = A_{,t} - B_{,t} - C_{,t} - D_{,t} \tag{8}$$

In the formula:

$E_{,t}$	In year t, the net carbon sequestration of the project, (t C) or (t CO_2);
$A_{,t}$	In year t, the afforestation carbon storage of the project, (t C) or (t CO_2);
$B_{,t}$	In year t, emissions within the project boundary, (t C) or (t CO_2);
$C_{,t}$	In year t, leakage outside the project boundary, (t C) or (t CO_2);
$D_{,t}$	In year t, baseline carbon storage, (t C) or (t CO_2).

3. Results and Analysis

3.1. Carbon Stock Change in the Baseline Calculation Period

The baseline calculation period was 20 years, with 2014 being the first year of the calculation period. In the study, the calculation method of the carbon stock of the trees, shrubs, and grass was used to measure their carbon sequestration in the baseline calculation period. At the same time, based on the selection of carbon pools for carbon stock accounting (the above-ground biomass and below-ground biomass), the carbon sequestration of the trees, shrubs, and grass was converted into the carbon stock of the above-ground and below-ground biomasses to explore the carbon sequestration dynamics of each carbon pool in the baseline calculation period.

The carbon stock change in the baseline calculation period showed that in the first 7 years, the annual carbon sequestration increase was 0.64 t (0.46 t C for above-ground vegetation and 0.18 t C for below-ground vegetation); in the last 13 years, the annual carbon sequestration increase was 1.19 t (0.88 t C for above-ground vegetation and 0.31 t C for below-ground vegetation), increasing by 86% compared with the first 7 years. In the first 7 years, the annual CO_2 sequestration increase was 2.35 t (1.69 t for above-ground vegetation and 0.66 t for below-ground vegetation); in the last 13 years, the annual CO_2 sequestration increase was 4.37 t (3.23 t for above-ground vegetation and 1.14 t for below-ground vegetation). At the end of the baseline calculation period, the cumulative carbon sequestration was 27.74 t C (20.22 t C for above-ground vegetation and 7.52 t C for below-ground vegetation), and the cumulative CO_2 sequestration was 101.85 t (74.22 t CO_2 for above-ground vegetation and 27.62 t CO_2 for below-ground vegetation), up to 5.09 t CO_2 for the annual average and increasing by 2.29 times compared with that at the beginning of the baseline calculation period (Table 4).

Table 4. Carbon stock change in the baseline calculation period.

Year	**Carbon Stock/t C**			**Carbon Stock Change/t CO_2-e**		
	Above-Ground Biomass	**Below-Ground Biomass**	**Total**	**Above-Ground Biomass**	**Below-Ground Biomass**	**Total**
1	6.02	2.41	8.43	22.09	8.84	30.94
2	6.48	2.59	9.07	23.78	9.50	33.29
3	6.94	2.77	9.71	25.47	10.16	35.64
4	7.40	2.95	10.35	27.16	10.82	37.99
5	7.86	3.13	10.99	28.85	11.48	40.34
6	8.32	3.31	11.63	30.54	12.14	42.69
7	8.78	3.49	12.27	32.23	12.80	45.04
8	9.66	3.80	13.46	35.46	13.94	49.41
9	10.54	4.11	14.65	38.69	15.08	53.78
10	11.42	4.42	15.84	41.92	16.22	58.15
11	12.30	4.73	17.03	45.15	17.36	62.52
12	13.18	5.04	18.22	48.38	18.50	66.89
13	14.06	5.35	19.41	51.61	19.64	71.26
14	14.94	5.66	20.60	54.84	20.78	75.63
15	15.82	5.97	21.79	58.07	21.92	80.00
16	16.70	6.28	22.98	61.30	23.06	84.37
17	17.58	6.59	24.17	64.53	24.20	88.74
18	18.46	6.90	25.36	67.76	25.34	93.11
19	19.34	7.21	26.55	70.99	26.48	97.48
20	20.22	7.52	27.74	74.22	27.62	101.85

3.2. Carbon Stock Change in the CSA Period

The carbon stock change in the CSA period showed that in the first 7 years, the annual carbon sequestration increase was 4.25 t (2.99 t C for above-ground vegetation and 1.26 t C for below-ground vegetation). The annual CO_2 sequestration increase was 15.61 t CO_2 (10.98 t CO_2 for above-ground vegetation and 4.63 t CO_2 for below-ground vegetation), nearly increasing by 7 times compared with that of the baseline calculation period. In the last 13 years, the annual carbon and CO_2 sequestration increase was 6.05 t (4.28 t C for above-ground vegetation and 1.77 t C for below-ground vegetation) and 22.19 t (14.80 t CO_2 for above-ground vegetation and 7.39 t CO_2 for below-ground vegetation), respectively, which was a 5-fold increase from that of the baseline calculation period. At the end of the CSA period (20 years), the cumulative carbon and CO_2 sequestration was 104.15 t C and 382.13 t CO_2, respectively, with an annual average carbon and CO_2 sequestration of 5.2 t C and 19.11 t CO_2, and the cumulative CO_2 sequestration was nearly 4 times that of the baseline period (Table 5).

Table 5. Cumulative carbon stock change in the CSA period.

Year	Carbon Stock/t C			Carbon Stock Change/t CO_2-e		
	Above-Ground Biomass	Below-Ground Biomass	Total	Above-Ground Biomass	Below-Ground Biomass	Total
1	0.00	0.00	0.00	0.00	0.00	0.00
2	2.99	1.26	4.25	10.98	4.63	15.61
3	5.98	2.52	8.50	21.96	9.26	31.22
4	8.97	3.78	12.75	32.94	13.89	46.83
5	11.96	5.04	17.00	43.92	18.52	62.44
6	14.95	6.30	21.25	54.90	23.15	78.05
7	17.94	7.56	25.50	65.88	27.78	93.66
8	22.22	9.33	31.55	80.68	35.17	115.85
9	26.50	11.10	37.60	95.48	42.56	138.04
10	30.78	12.87	43.65	110.28	49.95	160.23
11	35.06	14.64	49.70	125.08	57.34	182.42
12	39.34	16.41	55.75	139.88	64.73	204.61
13	43.62	18.18	61.80	154.68	72.12	226.80
14	47.90	19.95	67.85	169.48	79.51	248.99
15	52.18	21.72	73.90	184.28	86.90	271.18
16	56.46	23.49	79.95	199.08	94.29	293.37
17	60.74	25.26	86.00	213.88	101.68	315.56
18	65.02	27.03	92.05	228.68	109.07	337.75
19	69.30	28.80	98.10	243.48	116.46	359.94
20	73.58	30.57	104.15	258.28	123.85	382.13

By the end of the CSA term, the carbon sequestration of the coniferous standing forest (67.73 t C, 248.33 t CO_2-e) is higher than that of the broad-leaved standing forest (36.42 t C, F), accounting for 65% of the total carbon sequestration of the forest (104.15 t C, 382.13 t CO_2). The carbon sequestration of the tree species in the evergreen coniferous forest in descending order is *Picea koraiensis* (31.57 t C, 115.74 t CO_2-e), *Pinus koraiensis* (27.93 t C, 102.42 t CO_2-e), and *Larix olgensis* (8.23 t C, 30.17 t CO_2-e). That of *Pinus koraiensis* is 11.5% lower than that of *Picea koraiensis* and 70.5% higher than that of *Larix olgensis*; as for the broad-leaved tree species, the carbon sequestration of *Fraxinus mandschurica* is higher and over 20 times as much as that of *Populus cathayana* (1.65 t C, 6.04 t CO_2-e). The carbon sink density (the ratio of carbon sequestration of the standing forest to the area of the standing forest by the end of the project) of the coniferous standing forest (26.92 t C·hm^{-2}) is 8.7% higher than that of the broad-leaved standing forest (24.57 t C·hm^{-2}) (Figure 2).

The annual carbon fixation of the CSA standing forest (the ratio of carbon sequestration of the standing forest to the project duration, a, by the end of the project) is 5.21 t C·a^{-1}, with the coniferous standing forest (3.39 t C·a^{-1}) nearly doubling that of the broad-leaved standing forest (1.82 t C·a^{-1}). The highest carbon fixation belongs to *Fraxinus mandshurica*, closely followed by *Picea koraiensis* and *Pinus koraiensis* at a high level. That of *Larix olgensis* is relatively low, followed by the lowest performing, *Populus cathayana*. The carbon fixation of *Fraxinus mandshurica* is 20 times that of *Populus cathayana*. The carbon fixation rate of the CSA standing forest (the ratio of annual carbon fixation to the area of the standing forest) is 1.30 t C·hm^{-2}·a^{-1}, with a specific amount of 1.35 t C·hm^{-2}·a^{-1} for the coniferous standing forest and 1.23 t C·hm^{-2}·a^{-1} for the broad-leaved one (Figure 3).

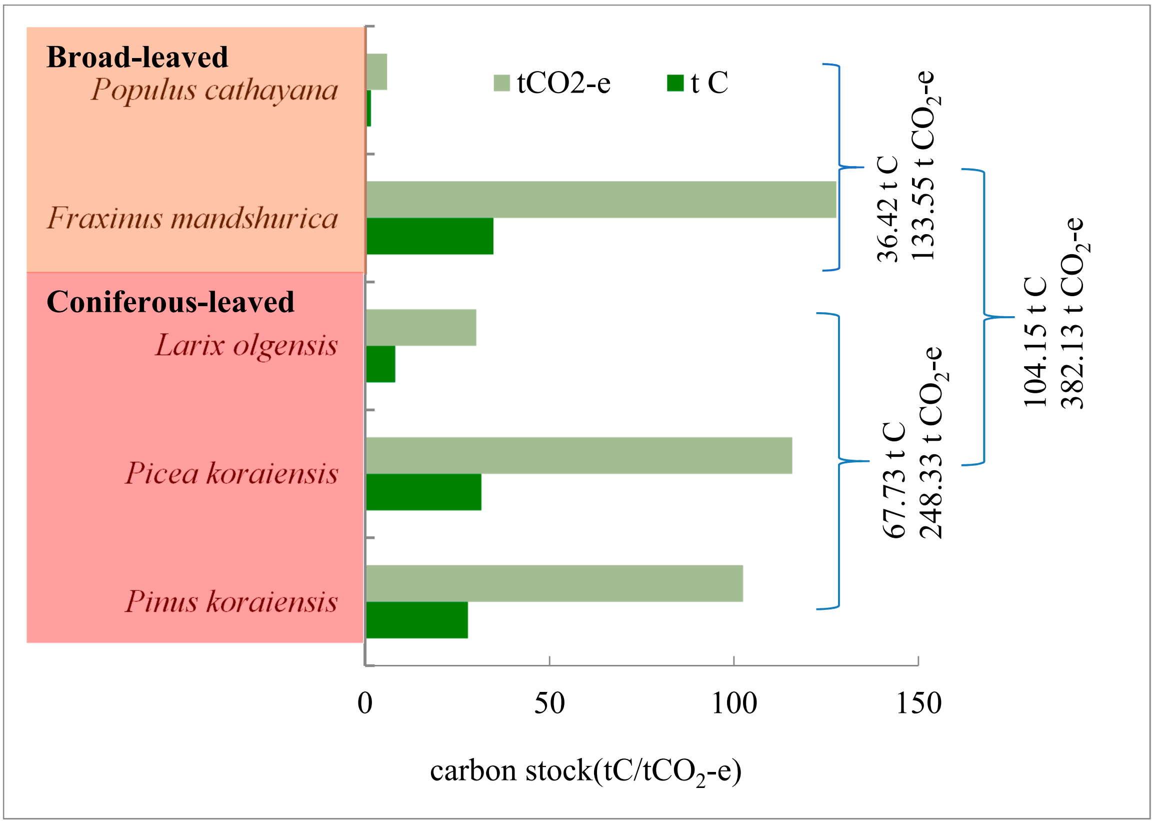

Figure 2. Carbon stock of arbor forest stand at the end of CSA.

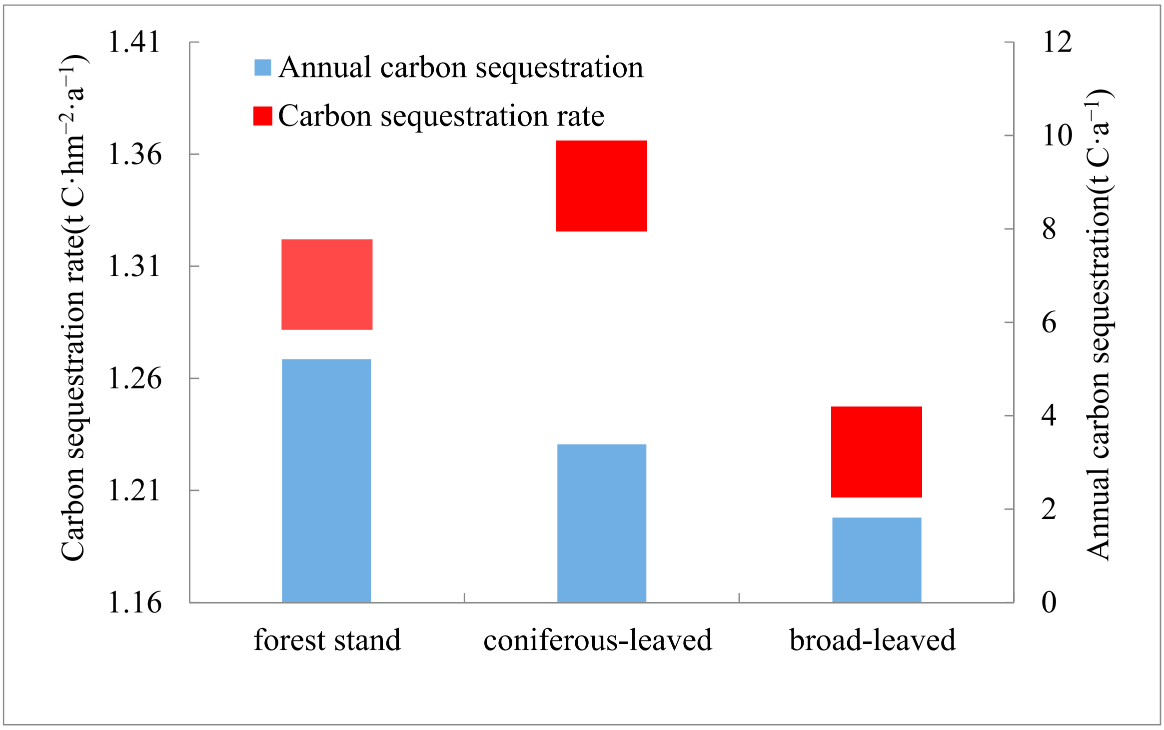

Figure 3. Carbon sequestration capacity of arbor forest stand at the end of the CSA.

3.3. Carbon Emission and Leakage

The carbon emissions were mainly N_2O and CO_2, resulting from fertilizer use and transport vehicles. Compound fertilizers were used as the base fertilizer (0.4 kg/plant), and organic fertilizer was used once in each of the first three afforestation years (0.5 kg/plant). The average load of transport vehicles was 5 t/vehicle, with an average transporting distance of 50 km and fuel consumption of 0.2 L/km. Therefore, within the project boundary, there was carbon emission in the first, second, and third years of the CSA period, which was 1.59 t, 0.47 t, and 0.47 t CO_2-e, respectively. The accounting showed that the cumulative greenhouse gas emission in the CSA period was 2.53 t CO_2-e. The carbon leakage from transport vehicles outside the project boundary occurred only in the first year (0.05 t CO_2-e) (Table 6). The carbon leakage research results showed that in order to reduce the CSA's carbon leakage, the seedlings should be cultivated near the CSA project area so as to reduce carbon leakage caused by long-distance transport.

Table 6. Carbon emission and leakage in the CSA period.

Year	Carbon Emission within the Project Boundary		Carbon Leakage Outside the Project Boundary	
	Annual Carbon Emission /t CO_2-e·a^{-1}	Cumulative Carbon Emission /t CO_2-e	Annual Carbon Emission /t CO_2-e·a^{-1}	Cumulative Carbon Emission /t CO_2-e
1	1.59	1.59	0.05	0.05
2	0.47	2.06		
3	0.47	2.53		
……				
Total	2.53		0.05	

3.4. Net Carbon Sink Estimation

The net carbon sink in the CSA period was the difference between the change of the afforestation's carbon stock and the sum of the change in the baseline carbon stock, carbon emission within the project boundary, and carbon leakage outside the boundary. The accounting results showed that the CSA was a carbon source in the first 3 years, with a −6.96 t CO_2-e cumulative carbon sink, and a carbon sink was formed in the fourth year, with an 8.84 t CO_2-e cumulative net carbon sink. At the end of the project in the calculation period, the cumulative net carbon sink was 280. 28 t CO_2-e, with an annual average net carbon sink of 14. 01 t CO_2-e (Table 7).

Table 7. CSA net carbon sink estimation.

Project Period	CSA Carbon Stock Change		Project Greenhouse Gas Emission		Carbon Leakage		Baseline Carbon Stock Change		CSA Net Carbon Sink	
	Annual Change (tCO_2-e·a^{-1})	Cumulative Amount (t CO_2-e)	Annual Change (t CO_2-e·a^{-1})	Cumulative Amount (t CO_2-e)	Annual Change (t CO_2-e·a^{-1})	Cumulative Amount (t CO_2-e)	Annual Change (tCO_2-e·a^{-1})	Cumulative Amount (t CO_2-e)	Annual Change (t CO_2-e·a^{-1})	Cumulative Amount (t CO_2-e)
1	0	0	1.59	1.59	0.05	0.05	30.88	30.88	−32.52	−32.52
2	15.61	15.61	0.47	2.06	-	-	2.38	33.29	12.76	−19.74
3	15.61	31.22	0.47	2.53	-	-	2.38	35.64	12.76	−6.96
4	15.61	46.83	-	-	-	-	2.38	37.99	13.23	8.84
…	…	…	…	…	…	…	…	…		
20	22.19	382.13	-	-	-	-	4.37	101.85	17.82	280.28

4. Discussion

4.1. Effect of Afforestation on the Carbon Stock of Forest Stands

Kong Lingjia's analysis of the carbon stock survey results of the forest of the Longjiang Forest Industry showed that during 2013–2016, the arbor layer carbon stock grew by 5.2% annually [34], which was similar to the accounting results that the annual average carbon stock in the carbon sequestration forest during the project period (20 years) increased by 5.0%. The reason behind this may be their similar vegetation types and geographic and climatic environment, as the two studied areas both belong to the forest zone of the Longjiang Forest Industry.

The afforestation design of this study is based on the afforestation standards of the Longjiang Forest Industry, aligning with the forest construction of the Longjiang Forest

Industry in afforestation plan, afforestation density, configuration method, and seedling specifications. The annual growth rate of carbon sequestration in the CSA in this study (5%) is a bit lower than that in Kong Lingjia's analysis of carbon sequestration in the Longjiang Forest Industry (5.2%). The main reasons could be that in this study, only the above-ground biomass, below-ground biomass, and soil's organic carbon were taken into consideration when estimating the carbon sequestration, while Kong also included litter, dead trees, and grass in the estimation besides the above ones; additionally, this study involved an arbor layer but without shrubs and herbs in the carbon sequestration accounting of the CSA.

The carbon density of the CSA by the end of the crediting period reached 26.04 t·hm^{-2} but still was only 47.6% and 40.9% of that of arbor forest in Kong Lingjia's study in 2013 and 2016, respectively [34]. According to a comparative study on tree, shrub, and herb composition and the carbon sink function between coniferous and broad-leaved forests in Northeast China from Wang Wenjie et al., carbon densities of coniferous and broad-leaved forests are 64.4 t·hm^{-2} and 51.3 t·hm^{-2}, respectively, and the average carbon density of the standing forest is 57.9 t·hm^{-2}, which is close to the findings of Kong Lingjia[34,35]. The carbon density results in both studies are higher than those in this study, which is possible because this study only involved the arbor layer in the carbon sequestration estimation of the CSA, while both Kong and Wang have taken shrubs and herbs into consideration in their studies; furthermore, the forests in their studies are natural forests, and differences on the methods of estimation and accounting could also lead to the varied results of the carbon density.

In this study, the carbon sink density of the coniferous standing forest (26.92 t C·hm^{-2}) is 8.7% higher than that of the broad-leaved standing forest (24.57 t C·hm^{-2}), which is similar to the results in the study of Wang Wenjie et al. that in northeast China, the carbon density of the coniferous forest (64.4 t·hm^{-2}) is 25.5% higher than that of the broad-leaved forest (51.3 t·hm^{-2}), while the proportion of carbon sequestration of the coniferous forest is much higher than that of the broad-leaved forest (13%), indicating that coniferous forest has higher carbon sequestration than the broad-leaved forest. Substantially, the carbon density of the coniferous forest is three times as much as that of the broad-leaved forest, which could be related to the ecological structure, such as forest community characteristics, carbon sink stability, and functional differences of the standing forest [35].

4.2. Effect of Afforestation on the Carbon Sequestration Capacity of Forest Stands

Liu Weiwei's study of the afforestation and reforestation effects on forest sequestration capacity showed that the carbon sequestration rate was 4–8 t C·hm^{-2}·a^{-1} in tropical zones and 1.5–4.5 t C·hm^{-2}·a^{-1} in temperate zones, and the rate in North America (0.7–4 t C·hm^{-2}·a^{-1}) was higher than that in Asia (0.23–1.38 t C·hm^{-2}·a^{-1}); in frigid zones, the forest sequestration capacity was below 1 t C·hm^{-2}·a^{-1} [36], which was relatively low. In this study, the carbon sequestration rate of the CSA forest stand was 1.30 t C hm^{-2}·a^{-1}, 71.5% lower than the minimum level in tropical zones and 14. 1% higher than that in the frigid zones. The rate was relatively higher in temperate Asian areas (5.65 times higher than the minimum level), indicating that the Weihe CSA pilot demonstration area in the Changbai Mountain of Northern China was a strong temperate forest carbon sink. The Weihe CSA has a relatively high potential for carbon sequestration, with its forest community characteristics and standing forest structure determined by the climate, site conditions, afforestation design, and scientific management, thus indicating that afforestation is the main driving force for forest carbon sequestration. Meanwhile, the afforestation area and its sequestration function are always finite, therefore establishing more scientific site-specific management of standing forests based on carbon storage and the differences between coniferous and broad-leaved forests in the broadening future of CSA's potential to enhance forest carbon sink storage and stability and effectively curb global warming.

In this study, the CSA was a carbon source in the first 3 years, and a carbon sink was formed from the fourth year, as the carbon density of vegetation gradually increased with the growing age of the forest. It was mainly due to the young forest age and weak carbon sequestration capacity of various forest categories in the first 3 years. Meanwhile, the carbon leakage caused by activity transfer, market leakage, emission transfer, and ecological leakage may offset the carbon sequestration effect of afforestation. Therefore, the carbon leakage caused by activities in afforestation and reforestation areas or surrounding forests should be minimized or avoided [37].

4.3. Analysis of Uncertainties in Accounting Research

This study was an accounting study of the hypothetical afforestation scenario. It forecasted and estimated the carbon stock and carbon sequestration capacity in the baseline scenario and CSA scenario according to relevant models and parameters of estimating live biomasses with the default method from the *IPCC's Technical Guidelines for National Forestry Carbon Sink Accounting and Monitoring*. The relevant systematic study was not in-depth enough. Afforestation behavior is a highly dynamic system with high spatial and temporal heterogeneity, and it can be affected by many uncertain factors, such as policy, environment, and management, which lead to uncertainties in the estimation results. In the future, carbon accounting studies of forest ecosystems should proceed with contrast tests and investigations so that the research results can better reflect the actual natural situation. Through the comprehensive adoption of various methods, multidisciplinary intervention, and integration and penetration, carbon accounting of the forest ecosystem can develop towards comprehensive and more integrated research.

5. Conclusions

The Weihe CSA has a relatively high potential for carbon sequestration, with its forest community characteristics and standing forest structure determined by the climate, site conditions, afforestation design, and scientific management, thus indicating that afforestation is the main driving force for forest carbon sequestration. Meanwhile, the afforestation area and its sequestration function are always finite, therefore establishing the more scientific site-specific management of standing forests based on carbon storage and the differences between coniferous and broad-leaved forests in the broadening future of CSA's potential to enhance forest carbon sink storage and stability and effectively curb global warming. According to relevant models and parameters of estimating live biomasses with the default method from the *IPCC's Technical Guidelines for National Forestry Carbon Sink Accounting and Monitoring*, carbon stock, emission, and leakage of the Weihe CSA pilot demonstration area in the Longjiang Forest Industry in the baseline scenario and CSA scenario were measured, and the CSA's net carbon sink was estimated. The accounting results show:

(1) The annual CO_2 sequestration increase was 2.38 t in the first 7 years of the baseline calculation period, and in the last 13 years, it was 3.96 t. At the end of the project's calculation period (20 years), it was 101.85 t CO_2. At the end of the project's calculation period (20 years), the cumulative carbon and CO_2 sequestration was 104.15 t C and 382.13 t CO_2, respectively, with the annual carbon and CO_2 sequestration averaging 5.2 t C and 19.11 t CO_2, respectively. The cumulative CO_2 sequestration was nearly four times that of the baseline period, with an annual average growth rate of 5%.

(2) By the end of the CSA term, the carbon sequestration of the coniferous standing forest accounted for 65% of the total carbon sequestration and was 46.2% higher than that of the broad-leaved standing forest. The carbon density of the carbon sequestration forest was 26. 04 $t \cdot hm^{-2}$. The carbon sink density of the coniferous standing forest was 8.7% higher than that of the broad-leaved standing forest. The carbon fixation of the coniferous standing forest nearly doubled that of the broad-leaved standing forest. The afforested tree species,

whose annual average cumulative CO_2 stock was arranged in descending order, were *Picea koraiensis*, *Fraxinus mandshurica*, *Pinus koraiensis*, *Larix olgensis*, and *Populus cathayana*. The carbon fixation of *Fraxinus mandshurica* was 20 times over that of *Populus cathayana*, therefore establishing more scientific site-specific management of standing forests based on carbon sequestration and the differences between coniferous and broad-leaved forests in the broadening future of CSA's potential to enhance forest carbon sequestration and stability.

(3) The cumulative greenhouse gas emission within the project boundary was 2.53 t CO_2-e, and the cumulative greenhouse gas leakage outside the project boundary was 0.05 t CO_2-e. To reduce the CO_2 leakage and emission from the CSA, it is suggested to raise seedlings near the project area to reduce CO_2 leakage and emissions caused by long-distance transportation, to reduce human disturbance in the project area, and to strengthen the protection of forest vegetation to further maintain and increase the carbon sequestration capacity of the forests and soil and to slow down the rise of CO_2 concentration in the atmosphere. Research shows that carbon emissions occur in the first, second, and third years of the crediting period, while carbon leakage only occurs in the first year. The reason is that in the first three years of CSA, the tree species are at their early ages, with weaker carbon fixation ability, while the carbon fixation from CSA could be offset by transport activities and ecological leakage.

(4) The CSA was a carbon source in the first three years, and a carbon sink was formed from the fourth year, with a net carbon sink of 280.28 t (70.07 t $CO_2\text{-e}\cdot\text{hm}^{-2}$) at the end of the project's calculation period. The findings showed that in temperate forests, the Weihe CSA pilot demonstration area was a strong carbon sink. The Weihe CSA has a relatively high potential for carbon sequestration, further indicating that afforestation is the main driving force for forest carbon sequestration. Meanwhile, the afforestation area and its sequestration function are always finite, therefore establishing more scientific site-specific management of standing forests based on carbon sequestration and the differences between coniferous and broad-leaved forests in the broadening future of CSA's potential to enhance forest carbon sequestration and stability and effectively curb global warming.

Author Contributions: X.W. contributed to the review and editing of the writing. K.M. and M.G. contributed to the motivation and interpretation of the methods. L.H. and Q.S. provided the data analysis. L.Z. and Z.Y. provided the draft versions and revised versions. Y.T., S.G., Y.X. and D.Z. provided the data results, the revised versions, and references. All authors contributed to the article and approved the submitted version. All authors have read and agreed to the published version of the manuscript.

Funding: This work was financially supported by the Heilongjiang Scientific Research Business Funds Competitive Project (CZKYF2022-1-B032); the Heilongjiang Jointly Guided Natural Fund Project (LH2021C093); The Heilongjiang Scientific Research Business Funds Non-Competitive Project (SCZ2022-02).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are in the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. López-Pacheco, I.Y.; Rodas-Zuluaga, L.I.; Fuentes-Tristan, S.; Castillo-Zacarías, C.; Sosa-Hernández, J.E.; Barceló, D.; Iqbal, H.M.N.; Parra-Saldívar, R. Phycocapture of CO_2 as an option to reduce greenhouse gases in cities: Carbon sinks in urban spaces. *J. CO2 Util.* **2021**, *53*, 101704. [CrossRef]
2. Kuttippurath, J.; Peter, R.; Singh, A.; Raj, S. The increasing atmospheric CO_2 over India: Comparison to global trends. *Iscience* **2022**, *25*, 104863. [CrossRef]
3. Gundersen, P.; Thybring, E.E.; Nord-Larsen, T.; Vesterdal, L.; Nadelhoffer, K.J.; Johannsen, V.K. Old-growth forest carbon sinks overestimated. *Nature* **2021**, *591*, E21–E23. [CrossRef]
4. Liu, M.X.; Shi, J.H.; Wang, X.Y.; Peng, Q.M. Effect of canopy density and age class on carbon sink function and carbon sequestration value of protection forest. *J. Northeast. For. Univ.* **2011**, *39*, 30–32.

5. Ren, J.Q.; Xia, J.Y.; Zheng, H.Y.; Sun, M.L.; Li, Y. Comparative study of publicized carbon sequestration afforestation projects and forest management carbon sequestration projects. *For. Eng.* **2015**, *31*, 55–58.
6. Rayner, P.J.; Law, R.M. The interannual variability of the global carbon cycle. *Tellus B Chem. Phys. Meteorol.* **2016**, *51*, 210–212. [CrossRef]
7. Zhang, Y.; Li, X.G.; Wen, Y.L. Forest carbon sequestration potential in China under the background of carbon emission peak and carbon neutralization. *J. Beijing For. Univ.* **2022**, *44*, 38–47.
8. Wang, W.F.; Chen, C.Y.; Wang, W.Q.; Sui, A.; Gao, X.L.; Liu, S.M. Research on the estimation and spatial distribution of forest carbon stock based on Muling subordinate forest farm. *For. Eng.* **2019**, *35*, 27–31.
9. Pei, J.; Niu, Z.; Wang, L.; Song, X.P.; Huang, N.; Geng, J.; Wu, Y.B.; Jiang, H.H. Spatial-temporal dynamics of carbon emissions and carbon sinks in economically developed areas of China: A case study of Guangdong Province. *Sci. Rep.* **2018**, *8*, 13383. [CrossRef]
10. Lin, B.; Ge, J. Carbon sinks and output of China's forestry sector: An ecological economic development perspective. *Sci. Total Environ.* **2019**, *655*, 1169–1180. [CrossRef]
11. Chen, K.; Cai, Q.; Zheng, N.; Li, Y.; Lin, C.; Li, Y. Forest carbon sink evaluation—An important contribution for carbon neutrality. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *811*, 012009. [CrossRef]
12. Liu, B.J.; Lu, F.; Wang, X.K. Greenhouse gas emissions and net carbon sequestration of the natural forest protection program in China. *Acta Ecol. Sin.* **2016**, *36*, 4266–4278.
13. Su, L.; Pan, M.Y.; Chen, L.R. A binomial tree option pricing model to assess the value of forestry carbon sink projects. *Issues For. Econ.* **2020**, *40*, 8–13.
14. He, X.; Chen, L.; Huang, Y. A study of forest carbon sink increment from the perspective of efficiency evaluation based on an inverse DEA model. *Forests* **2022**, *13*, 1563. [CrossRef]
15. Brilli, L.; Carotenuto, F.; Chiesi, M.; Fiorillo, E.; Genesio, L.; Magno, R.; Morabito, M.; Nardino, M.; Zaldei, A.; Gioli, B. An integrated approach to estimate how much urban afforestation can contribute to move towards carbon neutrality. *Sci. Total Environ.* **2022**, *842*, 156843. [CrossRef]
16. Shi, X.; Wang, T.; Lu, S.; Chen, K.; He, D.; Xu, Z. Evaluation of China's forest carbon sink service value. *Environ. Sci. Pollut. Res.* **2022**, *29*, 44668–44677. [CrossRef]
17. Huang, L.; Chen, K.; Zhou, M. Climate change and carbon sink: A bibliometric analysis. *Environ. Sci. Pollut. Res.* **2020**, *27*, 8740–8758. [CrossRef]
18. Cao, X.L.; Zhang, Y. Analysis on the China certified emission reductions, economic value and its sensitivity of Pinus kesiya var. Langbianensis afforestation project in Yunnan Province. *Ecol. Environ. Sci.* **2017**, *26*, 234–242.
19. Gong, R.F.; Yong, H.; Huang, W.W.; Zhang, X.Y.; Zeng, W.Z. Evaluation of forest carbon sequestration of northwest Sichuan CDM carbon project. *For. Econ.* **2015**, *37*, 38–41.
20. Gubiy, E. Analysis of carbon sequestration potential of forests of the asian russia. *Energy Systems Research* **2023**, *6*, 41–46.
21. Aweh, D.S.; Olotu, Y.; Ibrahim, R.; Izah, L.N. Assessment of deforestation impacts on carbon sequestration in Edo State south Southern Nigeria. *Technol. audit prod. reserves* **2023**, *70*, 6–12.
22. Goheer, M.A.; Fatima, L.; Farah, H.; Hassan, S.S.; Abbas, N. Assessment of change in forests land, carbon stock and carbon emissions of KPK, Pakistan for past three decades using geospatial techniques. *J. Water Clim. Change* **2023**, *14*, 442–453. [CrossRef]
23. Yu, S.H.; Zhou, G.M.; Shi, Y.J.; Lü, Y.L.; Shen, Z.m. Net carbon slnks ln the lnital stages otmoso bamboo stands. *J. Zhejiang AF Univ.* **2016**, *33*, 807–815.
24. Li, M.; Shi, Y.J.; Zhou, G.M.; Zhou, D.Y.; Zhang, J.; Zhang, Y.H. Measurement of carbon sequestration of highway afforestation in Jiaxing, Zhejiang, China. *J. Zhejiang AF Univ.* **2014**, *31*, 329–335.
25. Yuan, C.W.; Zhang, H.; Zhang, J.L.; Zheng, L.Y.; Sun, L. Measurement of carbon baseline storage of carbon sequestration afforestation in Jiangxia District, Wuhan City. *J. Cent. South Univ. For. Technol.* **2010**, *30*, 10–15.
26. Li, C.H.; Zhao, X.H. Research on coordinated development of ecological construction and economic transformation in state-owned forest area of Longjiang Forest Industry. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2019**, *62*, 144.
27. Zhang, M.Y.; Wei, S.Y.; Xu, R.; Wang, Y. Study on the sustainable management path of forests in state-owned forest region of Heilongjiang Province under the situation of transformation. *China For. Econ.* **2018**, *6*, 19–21.
28. He, Y.; Zhang, X.Q.; Liu, Y.X. Present status and potentiality of forest carbon trade market in China. *Cientia Silvae Sin.* **2007**, *43*, 106–111.
29. Pukkala, T. Calculating the additional carbon sequestration of Finnish forestry. *J. Sustain. For.* **2022**, *41*, 624–641. [CrossRef]
30. Gifford, L. "You can't value what you can't measure": A critical look at forest carbon accounting. *Clim. Change* **2020**, *161*, 291–306. [CrossRef]
31. Guo, H.; Zhang, S.C.; Xu, Y.H.; Zhang, R.Y.; Xing, S. Natural forest carbon sequestration value of forest area of Longjiang Forest Industry. *For. Eng.* **2012**, *28*, 95–98.
32. The Leading Group Office of the State Forestry Administration on Climate Change and Energy Conservation and Emission Reduction. *Guidelines for Carbon Accounting and Monitoring of Afforestation Projects*; China Forestry Publishing House: Beijing, China, 2008.
33. Wei, Y.D. Study on Carbon Accounting Methods of Afforestation and Reforestation Carbon Sink Projects in China. Master's thesis, Beijing Forestry University, Beijing, China, 2011.
34. Kong, L.J. Analysis of the forest carbon stock survey results of Longjiang Forest Industry. *For. Explor. Des.* **2021**, *50*, 44–47.

35. Wang, W.J.; Wang, K.; Wang, Y.Y.; Wen, H.; Yu, J.; Wang, Q.; Han, S. Comparative study on tree, shrub and herb composition and carbon sink function between coniferous and broadleaved forests in Northeast China. *J. Beijing For. Univ.* **2022**, *44*, 52–67.
36. Liu, W.W.; Wang, X.K.; Lu, F.; Ouyang, Z. Influence of afforestation, reforestation, forest logging, climate change, CO_2 concentration rise, fire, and insects on the carbon sequestration capacity of the forest ecosystem. *Acta Ecol. Sin.* **2016**, *36*, 2113–2122.
37. Huang, L.; Shao, Q.Q.; Liu, J.Y. Forest carbon sequestration and carbon sink/source in Jiangxi Province. *Acta Ecol. Sin.* **2012**, *32*, 3010–3020. [CrossRef]