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Carbon sequestration assessment in Kazakhstan's forests: analytical review

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ABSTRACT

Emissions of greenhouse gases in the atmosphere, which are predominantly carbon monoxide and carbon dioxide are led to the process of climate change that takes place on a global scale. This analytical review presents current knowledge and evaluates existing studies on carbon sequestration by forests in the world and in Kazakhstan. Forests play a key role in climate change, absorbing large amounts of carbon dioxide emissions from the atmosphere. They are the most important terrestrial carbon sink. Two key indicators can predict the level of carbon sequestration in forest ecosystems: biomass and productivity. Methods of assessing the sequestration of carbon dioxide by forests include the use of different models, such as inVEST, CO2FIX, and CBM-CFS3, among others. Forests have a three-fold role in climate change. They have been found to accumulate, absorb and allocate carbon dioxide gas. Because carbon sequestration of forest ecosystems in Kazakhstan has been poorly studied, there is a need for further research in this area. The development of afforestation and commercial forestry are the main recommendations for increasing the potential of carbon sequestration by forests. The development of these areas will promote an increase in efficiency and sustainable development of forest resources in the context of climate change adaptation.

KEYWORDS

climate change, carbon sequestration, forests

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1. Introduction

Climate change is taking place globally and is accelerated by a large amount of greenhouse gas emissions into the atmosphere, which are predominantly carbon oxide and dioxide. The concentration of carbon dioxide (CO2) in the atmosphere is the result of the carbon cycle between sinks and sources, as CO2 is a product of the oxidation of carbon that comes from these reserves (Karsenty et al., 2003). Research was conducted to study the effects of carbon dioxide on climate change, different ecosystems and economic sectors (Nevezhin, Shuvarikov, 2022; Sham, 2003).

Forests play an important role in climate change. They are the most important terrestrial carbon sink, while their biomass and productivity levels affect the level of carbon accumulation in ecosystems (Chang et al., 2017). However, forests can also contribute to carbon emissions through their destruction and degradation and are affected by climate change, drought and extreme weather conditions. With sustainable management, they can provide a unique environmental service, removing surplus carbon from the atmosphere and saving it in biomass, soil and wood products (Karsenty et al., 2003, p.iii). Therefore, afforestation and reforestation, as sources of carbon sequestration, are also ways to mitigate the effects of climate change.

Currently, studies aimed at assessing carbon sequestration, changes in carbon storage and the potential for carbon sequestration in forests are becoming relevant (Huang et al., 2020). This review will analyze the available data on the study of carbon sequestration by both forests worldwide and in Kazakhstan and provide a critical assessment of current research and published works.

2. The Role of Forests in Carbon Sequestration

Carbon sequestration is known to occur both naturally (through carbon sinks) and anthropogenically (via carbon capture and storage) (WECOOP Project, n.d.). Forests are natural carbon sinks, an important carbon reservoir that constantly exchanges CO2 with the atmosphere, both through natural processes and human activities. The process of photosynthesis explains why forests function as CO2 sinks, removing it from the atmosphere. Atmospheric CO2 is fixed in the chlorophyll parts of the plant, and the carbon is integrated into complex organic molecules that are then used by the entire plant.

According to several scientists' research (FAO, 2003) and based on several bioclimatic models, the absorption abilities of forest ecosystems in the world are quickly reaching their upper limit. They are expected to decrease in the future, perhaps even changing direction in the next 50-150 years. Global warming can lead to the strengthening of heterotrophic respiration, decomposition of organic matter, the simultaneous decrease of these sinks, and by doing so, turning forest ecosystems into sources of CO2 (FAO, 2003, Rohatyn et al., 2022). Also, an increase in forest coverage on a large scale can increase the availability of water by 6% in some regions but, in others, reduce it by 38% (Hoek van Dijke et al., 2022). Therefore, it is necessary to take measures to increase the ability of forests to capture and store CO2, and this phenomenon has been called "carbon sequestration" (WECOOP Project, n.d.).

Other studies (Coomes et al., 2012) emphasize the critical role of natural disasters (storms, snowstorms, earthquakes, and bark beetle attacks) in managing carbon flows in forests. Biomass losses due to tree mortality (especially in older stands exceeded annual increases for most of the 30-year study, moving 0.3 megatons of carbon from 1 hectare per year from biomass to detritus and atmospheric basins. Large-scale cataclysms are occurring in many forests around the world. These events are likely to be the driving factor determining the nature of carbon sequestration in forests in the next century. However, according to the author and other scientists (Popo-Ola et al., 2012), the degree of deforestation and forest degradation caused by anthropogenic activities has a stronger impact on forest destruction than natural disasters.

Thus, the contribution of forests to climate change is threefold: they are carbon pools that accumulate CO2; they become sources of CO2 during fires, or, in general, when they are disturbed by natural or human actions; they are CO2 sinks when they increase in biomass or expand their area. This means, that forests accumulate, absorb and release carbon dioxide. Wooden goods are also considered reserves of carbon (Zhao et al., 2022). In this review, forests are considered specifically as carbon dioxide sinks, which is the most generally accepted concept (FAO, 2003; National Report on the Inventory of Anthropogenic Emissions for 1990-2019, 2021; Kastornova et al., 2022).

Uneven territorial distribution and sparseness are typical for all forests of Kazakhstan. The main areas of highly productive coniferous and deciduous forests are concentrated in areas relatively provided with moisture: these are forest-steppe and steppe plain landscapes in the north and northeast and mountain landscapes of the Altai and Zhongar Alatau ranges in the east, the Trans-Ili Alatau in the southeast and the Tien Shan in the southwest. Saxaul forests are widespread in the desert zone, the ancient deltas of the large rivers Ile, Karatal, Syrdarya, Shu, as well as on vast sandy massifs and floodplains. Tugai forests are found in modern river valleys. Saxaul forests account for 51.77% of the total forest area of Kazakhstan (Fig. 1). These forests have high ecological value, protecting soils from erosion. Shrubs are common in almost all natural areas, along with woody and herbaceous vegetation (Interstate Commission on Sustainable Development, 2014).

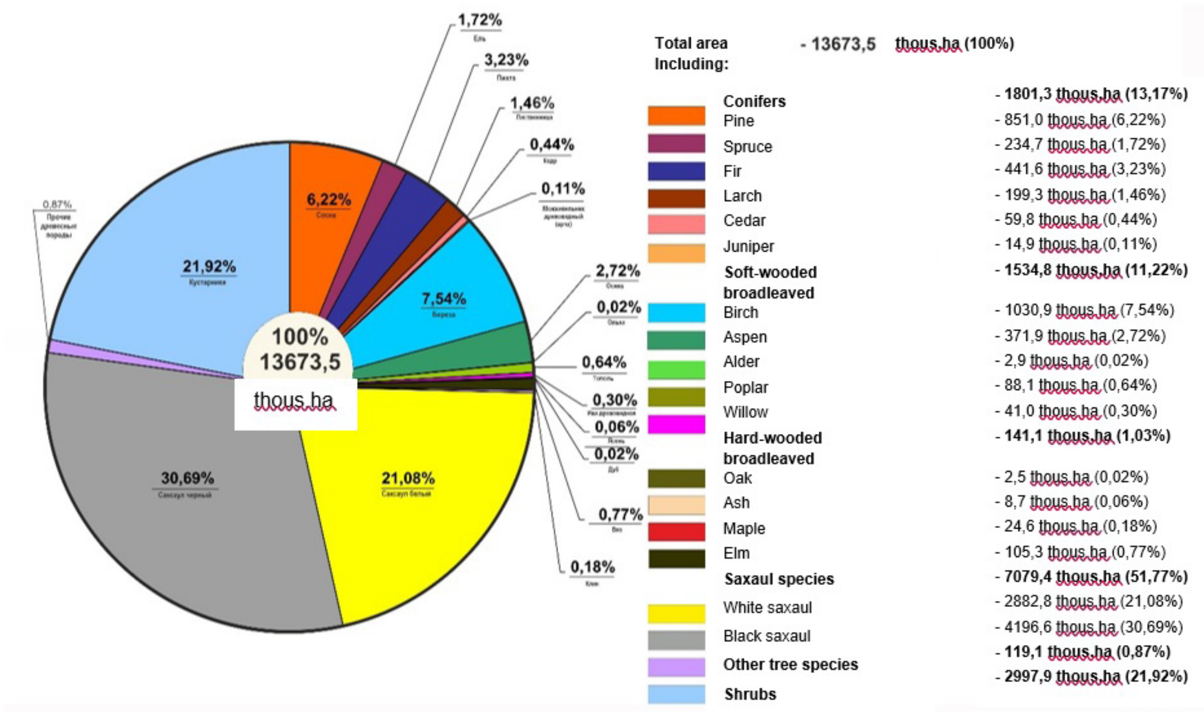

Fig. 1. Distribution of the area of forested land of the State Forest Fund of the Republic of Kazakhstan by predominant species as of January 1, 2023 (Committee of Forestry and Wildlife, 2022)

In 2021, the area of forest resources of the Republic of Kazakhstan was composed of 30.1 million hectares, and in 2022 – 30.552 million hectares. At the same time, the total area of the forest fund is 11.2% of the total territory of the country, and the area of forested land is 13,673.3 thousand hectares. In total, forest covers 5% of the Republic (Committee of Forestry and Wildlife, 2022).

3. Assessment Methods of Carbon Sequestration by Forests

Researchers use a variety of methods and models to assess forests' carbon sequestration potential.

In Sugi (Japanese cedar) forest plantations, indicators of total biomass, trunk biomass, and shoot biomass were used to calculate the carbon sequestration potential (Chang et al., 2017).

Based on the change in total carbon content from two different scenarios using the Markov chain and InVEST model, sequestration was estimated for 2000 and 2018 and forecasted for 2035 (Babbar et al., 2020).

Swedish scientists have developed a model consisting of an optimizing bench simulator using linear programming. In this model, carbon sequestration was considered in terms of carbon price, and its value was calculated as a function of carbon price and net carbon storage in the forest. (Backéus et al., 2005).

Models developed by scientists from Australia can be used to estimate productivity and total carbon sequestration (i.e. above- and belowground biomass) under a continuous range of planting patterns (e.g. different tree and shrub proportions or plant densities), time frames and future climate scenarios. Representative spatial models (1-hectare resolution) for three reforestation plans (forest patches, typical ecological plantations, biodiverse ecological plantations) × 3 time periods (i.e., 25, 45, 65 years) × 4 possible climate regimes (no change, mild, moderate, severe warming, and drying) were created (36 scenarios) for use in land-use planning tools (Hobbs et al., 2016).

Scientists from India have developed four allometric models using linear equations to estimate carbon capture four allometric models using linear regression equations between biomass (doubled carbon stock) and tree diameter, girth and height at different ages. Regression equations between biomass (doubled carbon stock) and tree diameter, girth and height at different ages. The diameter model was found to be more suitable for predicting carbon stock in similar areas (Jha, 2015). Other studies have used the CO2FIX dynamic growth model to estimate the carbon sequestration capacity of trees (Kaul et al, 2010).

In Kazakhstan, anthropogenic greenhouse gas emissions were estimated at the national level in accordance with the IPCC Guidelines for National Greenhouse Gas Inventories, 2006, Volume 4, Agriculture, Forestry and Other Land Uses (Interstate Commission on Sustainable Development, 2014; Strategy, 2023).

According to the Updated National Contribution of the Republic of Kazakhstan to the Global Response to Climate Change (2023), the CBM-CFS3 software was used to determine climate change mitigation through reforestation and afforestation under three different scenarios up to 2030. Also, the CBM-CFS3 model, fully adapted to the conditions of Kazakhstan, was used to simulate the afforestation of 1 hectare of flat land and the absorption of greenhouse gas emissions (Zhumabayev et al., 2022).

4. Results of the Study of Carbon Sequestration by Forest Plantations

4.1. Results of the study of sequestration in global forest ecosystems

Scientists have studied the sequestration potential of the Tarym River floodplain forests in China (Aishan et al., 2018), floodplain forests in Latvia (Saklaurs et al., 2022), mangrove forests in Indonesia (Analuddin et al., 2020), poplar plantations in Northern India (Arora, Chaudhry, 2015), and others.

Biomass and productivity influence the level of carbon storage in forest ecosystems, and the potential amount of carbon in a forest is determined by the amount of biomass. Therefore, the quantification of biomass is needed as a primary input of data to understand changes in the carbon pool and forest productivity (Sharma et al., 2017).

Forest biomass, and consequently sequestration capacity, is decreasing due to the clear-cutting of forest vegetation (Babbar et al., 2020). Calculations found that determining carbon storage in monetary value and removing carbon from forest products as a cost increase forest carbon sequestration and reduce harvesting (Backéus et al., 2005).

Current forests store about 45% of organic carbon in their biomass and soil. Natural forests contain more carbon in comparison to man-made forests and due to the complex structure of plantations, carbon storage underground and forest litter (Waring et.al., 2020). It has also been found that forests in national parks contain 40% more biomass compared to managed forests without logging (Krug, 2019). However, other scientists argue that forest plantations across a time span of 100 years show much higher rates of carbon dioxide absorption (Braakhekke et al., 2019). Due to the high age of forests in conservation areas, the role of natural forests as CO2 sinks is much higher than commercial forests. Carbon accumulation in old-growth natural forests is close to zero, but they still serve as carbon reservoirs (Adermann et al., 2015). On the other hand, young and middle-aged plantations absorb more carbon, as it is necessary for their growth and development. Some studies conclude that the main biomass reserves are contained in stem wood (Saklaurs et al., 2022). Since they are old-growth plantations that have large trunk diameters and volumes, they are the best carbon reservoirs. Thus, young and middle-aged forests have higher capture rates, and old-growth forests can be used for carbon storage.

4.2. Results of the Study of Sequestration in Kazakh Forests

The potential of carbon sequestration by forests in the Republic of Kazakhstan is poorly studied. However, scientists in Kazakhstan have developed databases on the distribution of organic carbon and its annual deposition by forests for different regions and the main forest-forming species (Baranov and Boranbay, 2014). According to their research, different species consume different amounts of carbon depending on their age and stock per hectare.

Research has determined (Thevs et al., 2013) the carbon stocks of Saxaul vegetation in Central Asian deserts. The living, aboveground biomass of Saxaul ranges from 1.5 tons per hectare to 3 tons per hectare. Potential carbon stocks above and below ground are 29.4 - 52.1 million tons and 22 - 81.4 million tons, respectively. However, due to illegal logging and overgrazing, only 11-28% of the potential biomass and carbon stocks in Saxaul forests remain today.

The sequestration potential of forests in Kazakhstan is determined by the increase in the area of reforestation and afforestation, which in 2020 amounted to 53.5 thousand hectares. In the same year, the absorption of greenhouse gases by forested lands and artificial forest plantations amounted to 37,600.4 thousand tons (World Bank, 2022). In order to increase forest cover, reforestation on public and private territories is carried out. In 2023, the Government of the Republic of Kazakhstan adopted the "Strategy for Achieving Carbon Neutrality of the Republic of Kazakhstan by 2060" (Strategy, 2023). According to the strategy, within the "Agriculture and Forestry, Other Land Use" sector, they specify what mitigates the effects of climate change. This mitigation is accomplished primarily through the absorption of greenhouse gases via carbon sequestration in soil and biomass, which occurs in forests, cropland, grasslands, wetlands, settlements and other lands throughout Kazakhstan. Thus, this sector is most often considered a carbon sink. However, in 2017, the overall balance changed, and this sector became a net emitter of greenhouse gases, which amounted to 0.2% of total emissions. As a result, at the end of 2020, Kazakhstan adopted a national tree planting plan, i.e. more than two billion trees in forests and 15 million trees in settlements should be planted by 2025 to increase carbon sequestration and curb increasing desertification (National Project "Green Kazakhstan", 2021).

According to the "Strategy for achieving carbon neutrality of the Republic of Kazakhstan until 2060" (2023), forest ecosystems within the LULUCF (land use, land-use change and forestry) sector should absorb 20.3 million tons of CO_2 by 2030 in an unconditional target of the total national level of contribution to the global response to climate change; by 2040, 28.3 million tons of CO_2, by 2050, 40.3 million tons of CO_2 at the indicative level; by 2060 - 45.2 million tons of CO_2 as a strategic goal with the condition of receiving international support (Strategy, 2023).

According to the "Inventory of Greenhouse Gases in Kazakhstan for 2022" (Fig. 2), the potential of carbon sequestration by forest plantations increased from 4412.53 thousand tons in 2016 to 10056.93 thousand tons in 2020, i.e. 2.5 times (UN Framework Convention, 2022).

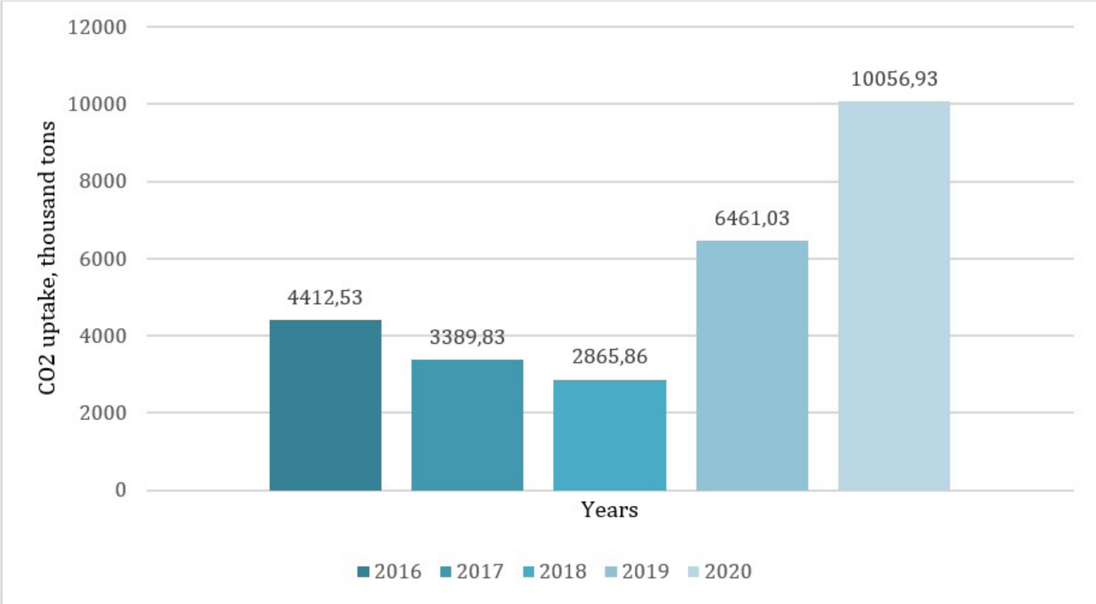

Figure 2. Carbon sequestration in Kazakhstan's forests for 2016-2020 in thousand tons (UN Framework Convention, 2022)

The CBM-CFS3 total national emissions level results in 2023 show that during the first three years (after planting), each hectare of coniferous or deciduous trees absorbs an average of 1 ton of carbon per year, equivalent to 3.67 tons of CO_2 per hectare per year in the absence of negative factors. However, this indicator decreased over time to 0.7 tons of carbon per year per hectare of forest due to fires, illegal logging and overgrazing. Thus, a 25-year lifespan of commercial forests (private forests) could provide adaptation benefits to the country as well as increase carbon sinks, offsetting anthropogenic emissions that cannot be mitigated or reduced by other means. Therefore, there is a need to grow private forests and develop commercial afforestation.

4.3. Carbon Sequestration by Different Tree Species

According to Roslesinforg (Ecology of Russia, 2021), the most intensive sinks are deciduous tree species: aspen - up to 3.6 tons per year/ha; birch – up to 3.3 tons year/ha, and oak – up to 3.2 tons per year/ha of CO_2. Coniferous wood species have a lower absorption potential: pine - up to 2.4 tons of CO_2 per year/ha; spruce and fir - up to 2 tons of CO_2 per year/ha; cedar - up to 1.8 tons of CO_2 per year/ha; larch - up to 1.8 tons of CO_2 per year/ha.

According to the CBM-CFS3 model (Zhumabaev et al., 2022), 1 ha of planted pine forest will absorb an average of about 7 tons of C02 per year from the date of planting and over the next 50 years. Hence, pine plantations or similar tree species with an area of 80 million hectares will absorb about 560 million tons of CO2 annually. The authors recommend the development of commercial afforestation in Kazakhstan. However, the limiting factors in the cultivation of pine trees may be a lack of water resources, maintenance work and high-quality planting material. Also, when growing pine trees, their biological characteristics must be considered. Thus, when studying the natural pine forests of the Irtysh region in Kazakhstan, it was noted that the determining factors of productivity, pine forests are characterized by geomorphological, soil and hydrological conditions. At the same time, the productivity of the biomass of plantations and environmental sustainability are weakened by sharp continentality and progressive aridization under adverse anthropogenic environmental influences (Zhumadina et al., 2022).

5. Practices to Increase Carbon Sequestration in Forests

According to some studies, an increase in carbon sequestration in forests directly depends on an increase in annual growth. Consequently, in order to achieve maximum forest stock, it is necessary to implement sustainable forest management that promotes the sustainable use of soil productivity (Fragoso-López et al., 2017).

Agroforestry practices include carbon sequestration by growing different types of trees, shrubs and other vegetation. Research conducted in Ecuador and Amazonia on the use of systems agroforestry in cocoa cultivation has shown an increase in the carbon potential of mixed plantations rather than in monocultures (Jadán et al., 2015). In Central Asia agroforestry practices, in particular protective forest belts, show high results for both wood production and carbon dioxide absorption (Thevs et al., 2022).

Many scientists believe that increasing the potential of carbon capture requires increasing forest productivity through logging, fertilization, and tree species selection (Jandl et al., 2007). At the same time, other scientists argue that an extended logging turnover in forests and a decrease in the intensity of logging can increase the ability of forest ecosystems to capture carbon in the long term (Kaul et al., 2010).

Some scientists believe that further sequestration in managed forests requires increasing the amount of carbon in the forest biomass. This is because of land-use changes and increased productivity, an amount of unyielding carbon remains underground after deforestation, and the amount of carbon contained in products created from harvested wood (Johnsen et al., 2001).

Reforestation will most effectively reduce emissions if trees are planted in highly productive areas previously covered with forest. Such sites are usually found in tropical or subtropical ecosystems. Planting mixed forests often increases productivity, reduces the impact of disturbances, and increases biodiversity compared to monocultures (Waring et al ., 2020).

In general, afforestation and the development of plantation forestry can significantly contribute to increasing forests' sequestration capacity.

6. Conclusion

Thus, based on the analysis of the available studies, the following conclusions can be drawn:

To assess the potential of forest sequestration, biomass and productivity must be considered as the main indicators.

Natural forests have more carbon storage potential than man-made and managed forests. However, over time, managed forests have a higher rate of carbon uptake. Therefore, it is necessary to develop commercial reforestation and restore forests in previously forested areas. The existing models for estimating sequestration in forest plantations do not meet all the requirements. Therefore, further research is needed to assess the potential of sequestration and model development.

Currently, the sequestration potential of forests in Kazakhstan has been poorly studied. However, data is available on some tree species and their absorption capacity, as well as on agroforestry and forest growing practices. Therefore, it is necessary to conduct research in the study of the ability of forests to capture carbon dioxide , as well as to increase the ability of forests to absorb carbon dioxide in Kazakhstan through forest growing and afforestation of territories.

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