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Reforestation is Not a Mitigation of Climate Change in All Situations – A Literature Review

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

Background: Environmental issues have gained widespread attention from all around the world and most of them originate from the root cause of climate change. Climate change occurs when there is increased concentrations of greenhouse gases in the environment, reflecting less heat back to space. In view of extreme weather and consequences, afforestation is now seen as one of the most effective methods in mitigating the effects of climate change. Increasing popularity of using forests as mitigation methods, however, does not translate to forests being effective solutions in all situations. Being part of our ecosystem, processes of forests are easily altered by climate change itself.

Aims: To ascertain if afforestation can effectively mitigate the effects of climate change in consideration that the processes of trees are affected by climate change itself.

Study Design: Literature review.

Methods: Data sources include Nature, Science Direct and environmental journals.

Results: Climate change currently increases the ability of forests to mitigate climate change but long-term exposure to increased temperatures and carbon dioxide (CO_2) levels reduce their abilities to do so. Location of where afforestation is carried out also affects the extent of effectiveness in reducing CO_2 levels and climate change.

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Conclusion: Afforestation can mitigate climate change if implemented appropriately, especially where it is effective. However, the primary solution will still be cutting carbon emissions since trees have a biological limit in response to climate change.

Keywords: Afforestation; terrestrial carbon sink; carbon sequestration; climate change; Global Warming.

1. INTRODUCTION

There is a general consensus that the actions of mankind has led to the enhanced greenhouse effect. Even before the industrial revolution, humans have been clearing trees to make space for anthropogenic activities. Today, croplands make up almost 35% of the Earth's land surface, the size of Africa and South America combined [1]. This large-scaled deforestation contributes to cumulative anthropogenic emissions by nearly 40% [1]. Industrialisation has also led to a massive amount of carbon emissions, whereby carbon is accumulating in the atmosphere at a rate of 3.5 Pg per annum, the largest contributor being the burning of fossil fuels [2]. This increased carbon dioxide (CO_2) concentrations has been predicted to cause us climate problems since decades ago [3].

Using his greenhouse model, Arrhenius (1896) showed that doubling atmospheric CO_2 would cause tropical latitudes to warm by 5ºC, with larger warming in the polar region. In contrast, reducing CO_2 by a third can cool global surface temperatures by -3ºC. Hence, the enhanced CO_2 level is the main reason behind terrestrial greenhouse effect.

Forests are directly involved in reducing the concentration of atmospheric CO_2. It is part of the carbon sink, participating in the assimilation and release of carbon. Being able to lower CO_2 concentrations via the processes of photosynthesis and carbon sequestration, afforestation is now a mitigation measure against climate change.

Many studies have been carried out to investigate how climate change affects the growth of trees as well as how trees can mitigate the effects of climate change. However, these studies do not have a clear relation between how the processes of trees being affected by changing climates reduce their ability to mitigate climate change. Climate change by definition is a climate shift due to human activities modifying the proportion of natural greenhouse gases in the lower atmosphere. It encompasses warmer temperatures and increased atmospheric CO_2. Having a direct influence on the factor inputs of tree processes, trees are extremely vulnerable to climate change.

In fact, long-term exposure to warmer climates and higher CO_2 levels are predicted to lower the ability of trees to reduce CO_2 concentration in the atmosphere. Increased recognition of forests being the silver bullet calls for a clearer analytical approach on how forests influence our environment.

Therefore, this review will be focusing on the effectiveness of trees on mitigating climate change with consideration of how the latter affects the former. Recently, the effectiveness of planting a trillion trees to reduce global CO_2 concentrations have been widely discussed internationally. However, other studies reveal that trees do not have such a simple effect on the environment. Essentially, a general relationship between forests and their ability to reduce CO_2 concentration in view of current changes of climate will be detailed and summarised in this review.

2. METHODOLOGY

This literature review involves an assessment of a variety of research papers from Nature and Science Direct.

The following search terms were used:

"Trees or afforestation or terrestrial or carbon sinks or forests" and "climate change or global warming or CO_2 or temperature" and "photosynthesis" and "carbon sequestration".

References related solely to agricultural land and carbon sequestration were excluded. References were classified according to forest types, components of climate change and how trees influence climate change. The search did not restrict the type of models used for prediction and identification of trends. The selection of the themes of references was a subjective one and was based on the abstracts.

3. THE CONTRIBUTION OF TREES IN TACKLING CLIMATE CHANGE

3.1 Photosynthesis

Photosynthesis is the process where plants absorb CO_2 for the synthesis of carbohydrates. At the global level, this process removes about 130 giga tonnes of carbon every year. This is 13 times more than that produced by anthropogenic activities [4].

Recent global warming has already caused a change in factors influencing photosynthesis. A study, “Carbon sequestration in Forest Ecosystem” by Lorenz and Lal [4] published that the rising trend of atmospheric CO_2 has a positive effect on the process. Analysis further reveals that current CO_2 levels are not high enough to saturate photosynthesis. More importantly, this study also showed that the positive correlation is only in the short term. Elevated CO_2 concentrations in the long term or further rises is projected to decrease photosynthesis. This effect can be highly aggravated by human-induced climate change if we were to believe that trees are benefiting from increased carbon emissions.

However, the effect of photosynthesis is close to insignificant. Studies on forests located all around the world show that photosynthesis is not the process that lower CO_2 levels. Trees absorb large amounts of CO_2 for photosynthesis but release an almost equivalent amount back through auto and heterotrophic respiration. The net lowering of CO_2 through photosynthesis is close to zero.

Instead, photosynthesis allows for carbon sequestration - a long term accumulation of carbon stored a biomass [5]. This storage accumulated in young trees accounts for significant carbon capturing ability of trees [6,7,8]. In a similar vein, long-term exposure to elevated CO_2 levels will lower the amount of carbon stored [9]. Trees may have the ability to decrease CO_2 levels, but climate change is reducing their effectiveness.

3.2 Carbon Sequestration

Carbon sequestration is the uptake of carbon containing substances, in particular CO_2, into a long-lived reservoir [4]. This process of carbon sequestration allows forests to store more than 80% of all terrestrial aboveground carbon and more than 70% of all Soil Organic Carbon (SOC) [10]. This high organic matter content makes forests the second largest carbon sink, after oceans. Carbon sequestration is also termed as biochemical effect exerted by trees on the environment.

Despite the increase in CO_2 emissions since industrialisation, atmospheric CO_2 concentration did not increase proportionately, allowing Working Group II of AR5 (Settele et al. 2014) to conclude that net terrestrial ecosystem productivity has increased as compared to the pre-industrial period, mainly due to enhanced photosynthesis stimulated by elevated CO_2 levels.

With temperatures following an upwards trend, this will impact the ability of forests to store carbon in different ways. Methodologically, net primary production (NPP) is used as a measure of the amount of carbon stored in carbon sinks.

3.3 Regional Carbon Sequestration

Reyer et al. [11] found strong regional differences in the growth of NPP in forests. Rising temperatures increased NPP over large areas of the Northern Hemisphere (NH) but generally decreased over the Southern Hemisphere (SH). 65% of vegetated areas in the NH increased in NPP, including large areas of North America, Western Europe, India, China, and the Sahel, whereas in the SH, 70% of vegetated land areas had decreased NPP, including large parts of South America, Africa, and Australia. Therefore, latitude and temperature are the dominant factors for plant growth together with carbon sequestration.

The increased productivity in NH was driven by lengthened growing season. Using a process model and climate scenario projections, [12] predicted that average regional productivity in forests in the Great Lakes region of North America could increase from 67 to 142%. This prediction came with the assumption that temperature rise and higher CO_2 levels are the main factors in influencing higher growth.

For vegetation covering in SH, temperature generally does not affect the growing season as indicated by an average of only 7.5 days of snow cover annually, in contrast to 125 days in the NH, as observed by MODIS [13]. Rather, lower temperatures directly constraints growth whilst higher temperatures directly reduces growth. The induction of a greater evaporative trend from warming appears to have a direct negative effect. It has been found that even the large amount of precipitation received in these regions is unable to negate this shortage of water.

Though NPP in the SH accounted for 41% of global NPP, the intensity of the decrease in this 41% far outweighs the increase in NPP over the NH. Furthermore, positive correlation between global temperatures and NPP were only present in areas with high latitude and altitudes, benefitting only 16% of the global NPP and 24% of global vegetated land area. This suggests that the positive correlation between higher temperatures and enhanced productivity does not have a global and uniform effect.

Given that 87% of forests currently experience a mean annual temperature above the ‘optimal’ temperature, further warming will no doubt lower the productivity of forest sinks, even for areas with higher latitudes and altitudes. Coupled with the findings of Boisvenue and Running [14] based on both satellite and ground based data, climatic changes seemed to have a generally positive impact on forest when water was not limiting. However, due to water scarcity, tree productivity will be lowered with future warming.

Another recent study reinforced this by showing a negative trend between higher atmospheric temperature and CO_2 uptake during summer [15], in contrast to an earlier study that showed a strong positive correlation during spring. As a result, if extrapolated to further warming in the next few decades, it leads us to hypothesise that further inactivity to curb carbon emissions can fundamentally disrupt high-latitude terrestrial carbon balance, reducing the ability of our forests to sequester carbon and alleviate the effects of global warming.

Generally there are significant challenges in detecting the responses of forests to climate change. The strong differences between the species of trees, type of forest and ecological conditions complicates the ecosystem level assessments [16].

Incorporating the effects of rising CO_2 levels also prove to be a challenge as most models predicting the effect of climate change on trees took on the assumption that increased CO_2 concentrations and temperature have significant influence over terrestrial productivity. Increased CO_2 levels have also been observed to stimula]te the efficiency of water use, but unable to offset the effects of increased water stress on growth [17,18]. Overall, the clear relationship between all trees and climate change has yet to be resolved.

4. FORESTS ARE NOT LONG-SOLUTIONS TO CLIMATE CHANGE

Forests operate both as mechanisms to absorb additional carbon and store carbon [2]. Young, growing trees undergo carbon sequestration, storing carbon as biomass, increasing the size of the carbon sink as they grow. As such, young growing forests are our trump card in decreasing CO_2 concentration.

However, a study found that accelerated tree growth exhibit hastened life cycles resulting in reduced longevity and wood density [19]. This suggests a trade-off between the long-term and short-term benefits of trees sequestering carbon. Trees sequestering carbon at an enhanced rate is likely to shorten the carbon residence time. Carbon stored will eventually be returned to the environment in a shorter period of time.

On a global scale, this short but fast life of trees limits the capacity of carbon sinks. Ultimately, while the rate of carbon uptake is faster, this shortened carbon residence time makes planting young, fast growing trees an ineffective solution in the long run.

This knowledge is one that is disconcerting, as increase in tree growth rate is supposed to result in higher carbon stocks. This assumption is one that can mislead and overstate the ability of trees in mitigating climate change.

5. LOCATION OF AFFORESTATION MATTERS

Trees exert biogeophysical effects on the environment [20,21,22,23]. The biogeophysical effect refers to climate change associated with changes in surface characteristics, namely evapotranspiration and the albedo effect.

The albedo effect, when applied to the Earth, is a measure of how much of the Sun's energy is reflected back into space. Forests being darker masses of land as compared to bare land absorb more solar energy from the sun and reflect less energy, and lead to warming of the environment [6].

Evapotranspiration is defined as the loss of water from soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it. The change of state of water from liquid to gas has a cooling effect on the environment.

Biogeophysical effects, evapotranspiration and the Albedo effect are directly influenced by the different environmental conditions at different latitudes. Specifically, afforestation at SH causes global warming but afforestation at the NH lowers global temperatures [17].

Snow-capped land at mountainous or higher latitudinal areas amplifies the effect of the Albedo effect. The darker contrast of forests as compared to snow further limits the ability of forests to reflect light. With snow reflecting up to 90% of light while forests reflecting close to 10% of light [21,24,6,25,26], the warming effect from the Albedo effect dominates. Meanwhile, more efficient use of water due to low precipitation received makes water loss via evapotranspiration almost insignificant [27]. Therefore, the net warming effect may have a global influence on rising temperatures.

In contrast, afforestation in the lower latitudes and tropical region can induce a cooling effect [24]. High precipitation received at lower latitudes enhances the process of water uptake, transpiration and evaporation, while less significant contrast between bare land and forests reduces the energy absorbed by forests. The cooling effect from advanced rates of evapotranspiration more than offsets the warming effect. Therefore, the net cooling effect experienced will be effective in lowering global temperatures.

In addition, Anderson-Teixeira et al. (2012) showed that northern forests have a relatively small net effect on global climate [23]. Instead, tropical forests have comparably higher capacities to store carbon and lower both regional and global temperatures. These forests exhibit greatest carbon stores, highest ability to impact local temperatures and alter global circulation pattern, thereby largely reducing global temperatures [24].

These findings guide us on the most effective and efficient way to mitigate climate change with the use of trees.

6. MELTING OF PERMA FROST

Carbon stored in soils of Arctic tundra and Boreal forests as permafrost has a capacity twice as large as the atmospheric carbon pool. Over the past few decades, this region has removed an average of 500 Tg carbon per year from the atmosphere [22,27].

Warming however, increases the susceptibility of these carbon sinks to decomposition, combustion and hydrolytic exports. A recent projection of permafrost soil carbon release suggests that the permafrost region will become a carbon source to the atmosphere instead of a carbon sink by 2100 if warming were to continue [28,29] (MacDougall et al 2012, Schuur et al 2013).

Whilst many models and experts predicted that boreal and Arctic forests will respond more quickly to warming with increased biomass production due to lengthened growing season as compared to soil carbon release from permafrost, these models do not take into account the factors affecting soil carbon release [30,31,32,33,34], thus overestimating the ability of boreal and arctic forests to sequester this additional carbon.

With factors such as fire and hydrologic carbon regimes taken into consideration, results show that contrary to previous models, the increase in biomass of arctic and boreal forests are unable to offset the increase in atmospheric CO_2 levels from permafrost acting as a carbon source [1].

Assessments showed that total permafrost-region biomass might decrease due to water stress from the drying effect of warmer temperatures. Also, organic carbon releases are likely to increase by almost 75% from collapsing coastlines and four times more from combustion due to increased frequency of wildfire.

As carbon release from permafrost is more strongly affected by these factors than the effect of warming on increased biomass, it is of high possibility that the carbon reservoirs in arctic and boreal forests are unable to take in all of the carbon released from the melting of permafrost.

This reinforces the importance of realizing that forests have biological constraints of their own. Afforestation can mitigate climate change but is unable to completely solve our problem.

7. DISCUSSION AND CONCLUSION

This review shows that while there has been considerable studies and analysis regarding climate change and carbon capture by trees, concrete projections on the effect of trees on climate change and vice versa shows diverse variation due to the difference in sample sites and models.

Understanding the effects of climate change on forests is challenging, but critical when intending to use them as mitigation against global warming. Detailed process-based ecosystem research which studies the effect of afforestation on natural feedback loops, coupled with model-based projections could provide invaluable information to guide future afforestation strategies.

With the current studies that we have now, we can only conclude that rise in CO_2 concentrations and temperature can alter the effectiveness of trees in mitigating climate change. Predictions also show that further worsening of the environment will reduce their ability to do. If, and only if we do not further raise carbon emissions, will afforestation remain as viable weapons to combat climate change? This needs to be focused in future research.

Analysis also shows that afforestation is not a “one size fits all” method. Afforestation in unsuitable latitudes and conditions can instead cause more harm to the environment. Countries lying in the NH and higher latitudes must make good and responsible decisions before afforestation. This involves recognising the potential effects of afforestation at this site via thorough research, proper planning and management for consequences. Countries lying in regions where afforestation has larger significance must put afforestation as priority.

Whilst it is common to see trees adapting to fit changes in environment over the years, all these studies and projections reinforces that trees have a biological limit. Forests can be effective mitigation methods against climate change, but there is a limit as to how much they can cushion the effect. We cannot solely depend on trees. More importantly, cutting carbon emissions must be our foremost solution.

Research studies and government initiatives that paint afforestation programme as the key to fighting climate change overestimates the ability of trees. The new study on how planting a trillion trees showed how the Earth still has sufficient space for the planting of these trees. But what it does not take into account is the effectiveness of carbon sequestration of trees in those areas. Out of the top five countries - China, Russia, Australia, the United States of America and Brazil that have the most room, almost four out of these five countries lie in the NH where afforestation will lead to warming instead of cooling. There is no doubt that afforestation can reduce CO_2 concentrations, but climate change encompasses both rise in CO_2 levels and temperature.

The future ahead is bleak and continued anthropogenic activities are likely to degrade the earth to a state where even trees are unable to reverse the damage.

A new report by the Intergovernmental Panel of Climate Change [9] showed that a reduction of expected increase in temperatures by as little as 0.5ºC can transform our fate. It will stop the melting of permafrost, reduced expansion of desert terrain and lower occurrence of extreme weather events all over the world. As such, despite the possible situation in store for mankind, we can change our fate if we are willing to do so. As discussed, trees will not be able to mitigate climate change in the long run. This leaves us with the only option cutting down carbon emissions. Therefore, governments and corporations should start to actively restrict pollution rather than to intensively plant trees in order to save our planet.

This review discussed how afforestation can be implemented to mitigate climate change most efficiently with the effects of climate change on trees taken into account. The myth that all trees can reduce climate change must be debunked and governments must work more closely together to fight climate change. Key challenges include reaching a common goal to reduce global warming and find a balance between the economy and the environment. If we are able to work together and learn to realise that the only primary solution to climate change is reducing carbon emissions, this dream will become a reality.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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