<u>Is it enough to plant trees- could this strategy help spread plant pathogens?</u>

Planting trees is an increasingly popular strategy to combat climate change, from keen environmentalists in their back garden to huge corporations like Shell promising to plant millions of trees as part of their $300 million campaign in order to reduce their carbon footprint[1]. It is often marketed as the “best weapon” against global warming, providing additional benefits including improved soil quality, protection from flooding and soil erosion, and habitats for wildlife. But afforestation, often of imported species, can lead to the spread of pathogens that threaten to wipe out our already dwindling numbers of trees. For example, Dutch elm disease was introduced to the USA in 1930 and, according to Phil McComb’s 2001 *Washington Post* article, ‘killed 77 million trees by 1970’. The streets once shaded by ‘great leafy high-arching cathedrals of elms’ lost their serenity in this disaster which he claims ‘changed the face of the nation’. The disease is caused by 3 species of the *Ophiostoma* fungi, and was spread to America by just one shipment of infected trees from Europe[2].

Undoubtedly, planting trees can be an invaluable asset to reduce climate change. A mature tree can absorb up to a maximum of 21.8 kilograms of carbon dioxide per year[3], and lock up the carbon as 25% of its wet mass until it decays. Estimates of global carbon dioxide emissions per year reach 40 billion metric tons. Forests’ function as a carbon sink means that our current rate of global deforestation, 120-150 thousand square kilometers per year, is completely unsustainable and contributes heavily to climate change, with up to 20% of carbon emissions being attributed to deforestation[4]. Figure 1 shows the effect of carbon dioxide emissions on global average temperature from 1959 to 2014.

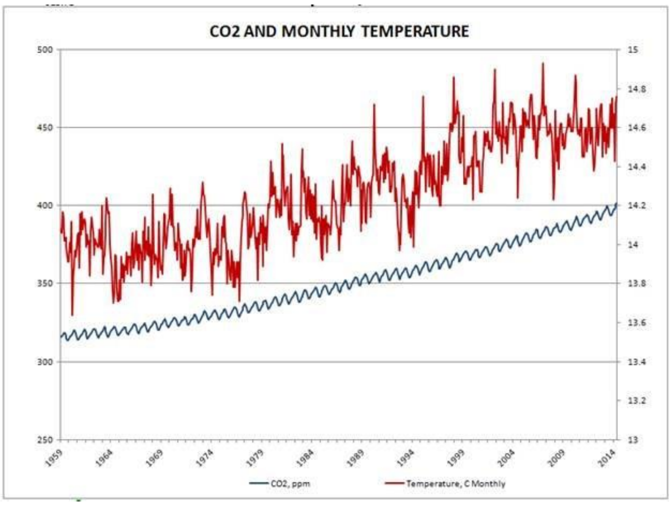

Figure 1: Watts, A. Accessed at https://wattsupwiththat.com/2014/09/12/a-look-at-carbon-dioxide-vs-global-temperature/ on 01/03/20

Deforestation often occurs for logging, livestock ranching or agricultural expansion to produce commodities such as soya and palm oil. Techniques such as slash and burn agriculture, where all trees are cut down and burnt so that the ash fertilises the soil (for only a couple of years until the farmer then has to do the same in a new plot of land), and clear cutting of trees for logging result in the complete deforestation of an area. This can, according to the National Aeronautics and Space Association (NASA), ‘permanently destroy’ the carbon sink. The importance of forestry in mitigating climate change has been recognised for a long time, with the Intergovernmental Panel on Climate Change (IPCC) stating in their first assessment report in 1990 that ‘a major decrease of the rate of deforestation as well as an increase in afforestation would contribute significantly to slowing the rate of CO2 concentration increase’[5], and in October 2018 that forests have an ‘unparalleled capacity to absorb and store carbon’ and could provide 30% of the solution to climate change.

However, not all trees are created equal in terms of their ability to absorb and store carbon. This is shown by the results of the international Bonn Challenge in 2011, a plan to plant 150 million hectares of trees by 2020[6]. Only 34% of the trees planted were part of a ‘natural forest’, while 45% were to be harvested quickly, and a further 21% were tree farm species such as cocoa, nuts and fruit. Monoculture plantations are far less powerful carbon sequesters, with natural forests storing up to 40x more carbon than these plantations. Monocultures have been documented as early as 1368, when *Pinus sylvestris* was grown for industrial timber. This is demonstrative of the issue with monoculture plantations: they are frequently planted for economic benefits, and the promise of mitigating climate change is tagged alongside. They present other ecological problems, such as significantly reducing biodiversity, heavy fertiliser and pesticide usage, soil degradation and pathogen vulnerability, as will be discussed later in this essay.

There are many more considerations to make when treating afforestation or reforestation as a catch-all solution to climate change. Unfortunately, there are many examples of planting trees that have had the opposite effects intended. A study in 2016 found that afforestation in Europe since 1750 has actually led to an increase in temperature of almost 0.12 Kelvin due to the harmful forest management and conversion from the original broad-leaved species to conifers[7]. Furthermore, in April 2016 there was a devastating wildfire in Fort McMurray, Canada, destroying 2,400 houses[8]. This was a result of the government-issued plan in the 1980s, converting the peat bogs to timber-producing black spruce forests. The natural wet peatland had been resistant to wildfires, but the drained area was vulnerable, releasing all the carbon stored in the trees when they burnt. Figure 2 shows the counterproductive effect the government’s action had.

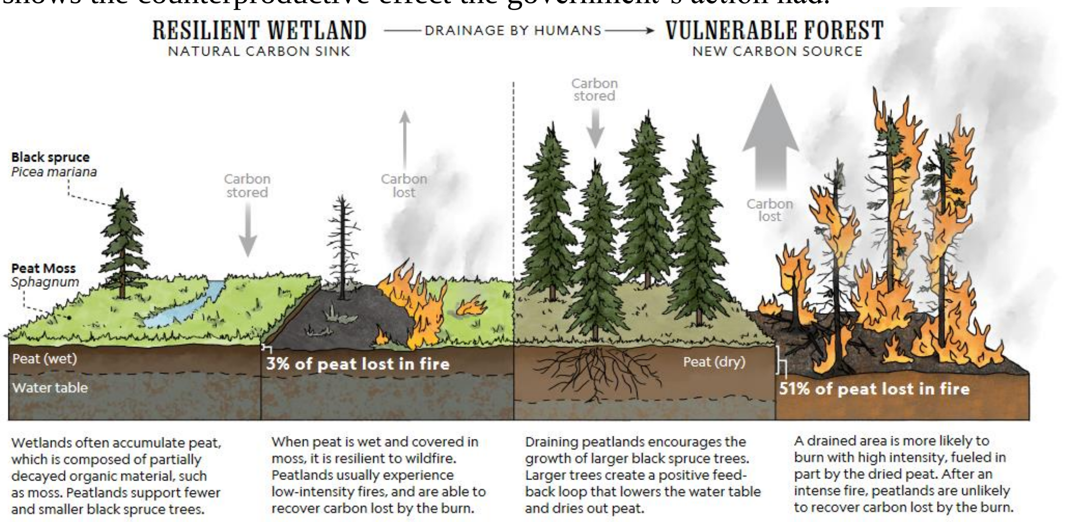

Figure 2 Maggiacomo, T., Champine, R. For National Geographic. Accessed at https://www.nationalgeographic.com/environment/2019/04/how-to-regrow-forest-right-way-minimize-fire-water-use/ on 26/02/20

Furthermore, while trees should be part of the climate solution, they are not powerful enough on their own. According to a study conducted by the Potsdam Institute in 2017[9], even if carbon dioxide emissions are limited in line with the 2015 Paris Agreement (aiming to limit temperature rise to 1.5˚C above pre-industrial levels), biomass plantations to remove excess emissions would have to replace more than 25% of current agricultural land, or fertile land in natural ecosystems more than 1/3 the size of our current forests. In a ‘business continued as usual’ scenario, the plantations required would replace almost all the natural ecosystems in the world, with devastating consequences. Therefore relying solely on trees would lead to incomprehensible choices such as feeding the growing global population or sequestering the necessary amounts of carbon.

A huge issue with the planting trees strategy is of course the spread of pathogens. Firstly, managed monoculture or clonal plantations with just one species representing a single genotype at high densities are extremely susceptible to pathogens. This is due to the lack of genetic diversity, meaning that if one tree is vulnerable to infection, it is likely that the rest are. There are many examples of this, for example the well-known Irish Potato Famine (1845-49) was so devastating because the majority of potatoes planted were lumpers, which were vulnerable to a rot the oomycete *Phytophthora infestans* caused[10,11]. The origin of *P. infestans* is considered to be in South America or Mexico, and it was introduced to Ireland from the Americas. The devastating blight caused over a million deaths directly from starvation and remains one of the most dangerous potato pathogens globally[12].

Further instances include the infection of the rubber tree *Hevea brasiliensis,* which is found in low abundance in its native Amazon forests[13]. In its native Amazon, the endemic fungus South American Leaf Blight, *Microcyclus ulei,* does little harm, but when *H. brasiliensis* is commercially grown in monoculture plantations in South and Central America, it is highly susceptible to an *M. ulei* infection which causes damage so significant that successful plantations are restricted to other continents where *M. ulei* isn't (yet) present.

Extending the range of a species of tree beyond its natural boundaries can lead to its endemic pathogens flourishing in the new environmental conditions and therefore severely damaging the planted tree. For example, the *Pinus radiata* tree is very cheap and manageable, making it economically attractive as a plantation species. It was forested around the world in many areas such as Chile, parts of East Africa and New Zealand[14], for use in the construction industry. The fungal pathogen *Dothistroma septosporum* can cause devastating needle blight in *P. radiata*, however cases in its native Northern hemisphere temperate forests are rare and damage is limited[15]. Plantations which both the host and pathogen have been introduced to in the Southern hemisphere are affected much more seriously by *D. septosporum*, due to the warm humid conditions present[16].

Furthermore, exotic forestry can lead to plantations which cannot withstand the environmental conditions. The stress of the climate lowers their resistance to local pathogens, allowing extreme pathogen damage. If this occurs to a great enough extent, the pathogen pressure in this local area can become too high for the adapted native species that surround it, leading to damage among these trees as well. For example, this may have caused the increased damage in the last 20 years of the earlier mentioned *D. septosporum* in England on the native *P. sylvestris,* as the imported *P. contorta* plantations are susceptible to outbreaks[17,18].

The 'most serious threats'[19] to forests, however, are those presented by exotic pathogens transmitted by their related exotic species. Like the aforementioned American elm trees, the American chestnut tree was devasted by the introduction of a foreign pathogen, *Cryphonectria parasitica.* The fungal pathogen was accidentally brought to the USA from Asia in the early 1900s, and spread swiftly, killing the once magnificent trees as it went. By 1950, it had entirely annihilated the American chestnut tree as a mature species by 1950. More recently, since 2012 in England we are beginning to see the potentially devastating impact of the disease ash dieback, caused by the fungal pathogen *Hymenoscyphus fraxineus*[20]. England's native ash species, *Fraxinus excelsior*, is very susceptible to the disease, as, it is believed, all the ash species are to varying degrees. It is estimated 95% of all ash trees may be lost to ash dieback[21]. H. fraxineus is originally from Asia, however the trees there have coevolved with the pathogen, meaning they have built some genetic resistance and are far less badly affected.

The likelihood of an exotic pathogen being able to infect local trees is fortunately low. The smaller the evolutionary distance between the exotic hosts and native trees is, the more probable it is that the pathogen will be able to infect the trees[22]. According to Richard Ennos, 'exotic pathogens can have such devastating effects that even very low probabilities of establishment of exotic pathogens on native trees represent serious risks to forest health'[23].

Therefore, it is clear that strategies of afforestation can and have led to the destruction of tree species. According to an article published in 2013 in *Science*[24] outbreaks of dangerous pests and pathogens are increasing across the world, due to, as discussed earlier, the introduction of tree species beyond their natural range, where they are unlikely to have any evolved resistance. Climate change also worsens the vicious cycle of tree death. Tree species are planted in an effort to strengthen the carbon sink, but the changing environment affects the range of both trees and infecting pathogens, and further increases physical stress on trees, making them more vulnerable to infection, and therefore increasing tree mortality and decreasing carbon absorbed.

However, there is an increasing amount of research into the most effective strategies of afforestation, for both forest health and the global climate. The most important aspect, according to Crystal Davis at the World Resources Institute (WRI),is that ‘ restoration is at the local level, by factoring in local considerations and local needs’ instead of faraway governments blindly planting trees. This means considering the history of any deforestation in the area, the native species and the local climate and ecosystem and, according to Saul Elbein in a National Geographic article, ‘removing obstacles and getting out of the way’[25]. While planting the native species is ideal, where this is impossible, scientists are researching how to help vulnerable species build resistance. For example, in a 2019 study, the genomes of 1250 ash trees were sequenced in an attempt to increase resistance against ash dieback[26], an extremely destructive disease explained earlier in this essay. They concluded that ash dieback resistance was controlled by multiple genes, and should react positively to human intervention, such as breeding, as well as natural selection. In addition, there are many preventative measures taken by governments to inhibit pathogen spread, from prohibiting the importing of trees known to be affected to public organisations such as the Animal and Plant Health Agency, which can provide guidance.

To conclude, natural forests are intricate ecosystems vital to humans in innumerable ways, from providing food to their value in promoting mental well-being. One of their most valuable functions is as a carbon sink, hence why afforestation and restoration have become such a popular strategy in combatting global warming. The best way to harness forests’ power in mitigating climate change is to stop deforestation as much as possible, and reforest in the sustainable manner described above. Planting trees is, as Ken Cadeira said, ‘an appealing, feel-good thing’[27], but can unequivocally not be treated as the solitary solution to climate change. As outlined earlier, this is because the anthropogenic monoculture plantations frequently created are nowhere near as powerful carbon sequesters as the tropical rainforests we continue to destroy, and because not enough consideration is taken in choosing the species, location and management of the trees planted. Finally, human intervention has definitely led to the increasing spread of pathogens. Through monoculture plantations that offer more financial than environmental benefits, we risk a pathogen wiping out the whole plantation, with consequently disastrous economic impacts. Exotic pathogens threaten native and planted forests, and vice versa. Further accentuating these factors, climate change exacerbates the vicious cycle by increasing tree mortality. Looking forwards, we should adopt the preventative and thoughtful measures presented earlier, undertake further research, and employ the new DNA sequencing techniques to support an overall multi-stranded and flexible approach to mitigating climate change.

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