The Application of Drones in Ecological Restoration – An Analysis

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Abstract

This dissertation assesses the feasibility of drone technology as a potential solution to the multitude of issues caused by the continuation of large-scale deforestation around the world. In order to achieve this assessment, several objectives were defined:

- Understanding the need for intervention regarding the prevention of deforestation – identifying any areas in particular which may benefit from the technology.
- Investigating the companies which design and operate drones used for ecological rehabilitation. In addition, understanding how these companies can make reforestation efforts less challenging and more obtainable.
- Research into how the drone technology functions at a practical level to produce the results necessary for large scale reforestation.
- Comparing the different factors attributed to traditional reforestation methods against that of reforestation with the use of drone technology.
- Researching the energy and material consumption involved in the construction of drones.
- A theoretical analysis on how implementing large scale reforestation would affect C02 levels and biodiversity.

Through the continued destruction of forests, many habitats, livelihoods and environmental goals are put at risk in an unsustainable manner. Developing countries who participate in a significant amount of deforestation are the most at risk of being disadvantaged by the issues which are a consequence of deforestation.

Reforestation projects are often labour intensive, expensive, and slow; hence why forests are destroyed faster than they can be rehabilitated. Drones can potentially aid in speeding up reforestation work and become a useful economical addition to many projects. Drones do have disadvantages such as lower survival rates compared to traditional methods, though with further innovation they have the possibility to scale up reforestation efforts on a global scale

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1. Introduction

Forests have been an integral part of the natural world for millions of years – providing humans and animals alike with countless benefits and nourishment. Covering only around 30% of the world's land mass, forests contain 80% of the terrestrial biodiversity found on Earth. Furthermore, 1.6 billion people depend on these forests to survive through the provision of food, water, fuel and shelter (European Commission, 2021). From this information alone, it would be accurate to state that without forests; life on Earth would not be possible.

Through technological advancements in recent years, the use of drones has become more prevalent in society - from consumer gadgets to military drone strikes. With very little advancements made with regard to reforestation methods since now, drone technology may hold the answer to the ever-growing problem of deforestation. The use of drones allows for the possibility of cheaper, less labour intensive, international-scale reforestation efforts. This advancement may further promote the benefits of reforestation; while increasing the extent to which communities, companies, and governments can afford to participate.

This dissertation aims to assess the feasibility of drone technology becoming a vital solution and driver for reforestation and sustainable forest management. Furthermore, as the use of drones in reforestation is a relatively new concept, it is the intention of this dissertation to further expand on the available literature on the subject and in doing so further promote the topic within the environmental community. Assessment into the possible solution drones present will be achieved through:

- Understanding the need for intervention regarding the prevention of deforestation – identifying any areas in particular which may benefit from the technology.

- Investigating the companies which design and operate drones used for ecological rehabilitation. In addition, understanding how these companies can make reforestation efforts less challenging and more obtainable.
- Research into how the drone technology functions at a practical level to produce the results necessary for large scale reforestation.
- Comparing the different factors attributed to traditional reforestation methods against that of reforestation with the use of drone technology.
- Researching the energy and material consumption involved in the construction of drones and the use of them for reforestation – does this offset the possible advantages of this technologies use?
- A theoretical analysis on how implementing large scale reforestation would affect C02 levels and biodiversity.

1.1 Growing need for ecological intervention

Despite areas of the world such as Europe – that in 2010 had increased forested areas by 11 million hectares (ha) since 1990; climate change and deforestation destroys more plant life than can be regenerated by nature alone. This simultaneously releases more C02 into the atmosphere and reduces the capacity for natural carbon storage (European Parliament, 2020). If climate change is to be tackled, this trend cannot be allowed to continue. The consequences of deforestation risk the advancement of numerous Sustainable Development Goals developed by the European Commission. These include, but are not limited to: an increase in extreme weather; decrease in rainfall and insect pollinators for crops; increased respiratory illnesses due to wildfires; unsustainable water resource management; unsustainable economic growth including income inequality; C02 emissions; loss of biodiversity; and a rise in patterns of unsustainable resource consumption (European Commission, 2019).

Many developed countries, such as within the EU, have had the luxury of benefitting from large scale industrial activities in the past. Though in recent years as scientific research has pointed out the extent of the damage these human activities have had on the environment; allowing developed, more financially stable countries to have the option to mitigate and improve through environmental policies, initiatives, and conservation. Meanwhile, industrial or developing countries still contribute significantly to deforestation through commercial/subsistence agriculture, livestock grazing, timber extraction/fuel wood, and mining (Hosonuma, et al., 2012). Despite centuries of deforestation, the typical methods for reforestation have remained relatively unchanged. It is labour intensive, requires a large on-site workforce, and is often expensive.

Reforestation is a challenging process which yields slow results. Yet the rate at which forests continue to be lost due to the human activity, and natural imbalances as a consequence of climate change will not subside to an extent which could correct these imbalances. Currently an approximation of 4 billion ha of forest still stand, though since 1990 an estimation of 420 million ha of forest has been lost, primarily in Africa and South America (United Nations, 2020). Figure 1 below illustrates the 10 countries with the highest net loss of forests. As stated above, many of these countries are in the midst of their industrial revolutions, following in the footsteps of now more developed countries – they perceive profit from deforestation outweighs the benefits of the forest areas and mitigation of climate change.

Ranking	Country	Annual net change	
		1 000 ha/yr	%
1	Brazil	-1 496	-0.30
2	Democratic Republic of the Congo	-1 101	-0.83
3	Indonesia	-753	-0.78
4	Angola	-555	-0.80
5	United Republic of Tanzania	-421	-0.88
6	Paraguay	-347	-1.93
7	Myanmar	-290	-0.96
8	Cambodia	-252	-2.68
9	Bolivia (Plurinational State of)	-225	-0.43
10	Mozambique	-223	-0.59

Note: The rate of change (%) is calculated as the compound annual change rate.

Figure 1 - Top ten countries for average annual net loss of forest areas, 2010 – 2020 (Food and Agriculture Organization of the United Nations, 2020)

Around half of the world's forests are within the domain of developing countries where deforestation rates remain too high. Research has shown clearly that national wealth corresponds strongly with deforestation rates. Countries with higher GDP's perform better in reforestation and conservation than developing countries with low GDP's (Keenan, et al., 2015). This is to be expected – more resources equate to better potential to mitigate deforestation and climate change. The United Nations framework for action on climate change, deforestation, and ecosystem loss states that those in poor rural communities will be the worst affected by the continuation of deforestation at current levels. This framework was written in 2010, and as a part of the conclusion of research, stated that more resources are likely to become available for intervention, due to the increasing urgency of climate change (United Nations Development Programme, 2010). Although not prophesised, one of these resources could be the introduction of drone technology. With supposed cost reductions of this method of reforestation and forest management, it may present an economical solution for developing countries who are limited in resources to combat these environmental issues.

2.Review of Literature

2.1 Background on drones

There are many names attributed to the technology of Unmanned Aerial Vehicles (UAVs); though the most common term used is ‘drones’. Defined as UAV by the International Civil Aviation Organisation in 2005, before the introduction of small-scale recreational drones; the public were only familiar with the technology in terms of its military use in the Middle East. Understandably, this gave the technology connotations of death and destruction (Bartsch, et al., 2017). Drone technology can range in size, cost, design, and capabilities depending on the intended purpose. Many consider drones to be the most important innovation in aviation since the Wright brothers first invented the airplane in 1903. Within the last decade, drones have become a widely available and a popular gadget to own for the general public, governments, and enterprises alike. The popularity of drones stems from the extensive range of functions the technology can facilitate, from competitive drone racing, photography and filmmaking, to military operations. With rising popularity of drones many concerns have been raised. These concerns include:

- Intentional threats to privacy or security
- Use of drones to cause physical harm to people
- Carrying and intentionally dropping hazardous payloads onto people or in the environment
- Risk to air traffic through intentional crashing or accidental collisions

With popularity rising and costs decreasing, drones have and will continue to become more prevalent in society, so there are questions to be asked as to what is acceptable in regard to ethical use and what should be allowed legally (Custers, 2016). One of the UK’s largest airports saw significant disruption to flights due to the intentional illegal misuse of a drone flying over airport-controlled airspace. This dangerous misuse forced one plane carrying 186 passengers to divert course, providing an example of how drones can be used for nefarious purposes (BBC, 2019).

Nevertheless, with the further innovations in drone technology, the possibilities of how they can be used in a positive manner continue to expand. These possibilities include aiding law enforcement, inspection of infrastructure, collection of meteorology data, assisting emergency services, agriculture, and even parcel delivery (Vergouw, et al., 2016). Among the variety of functions drones can be utilised for, there is an emerging market for drones to be utilised for the benefit of the environment. Specifically drones which can help solve the problem of deforestation on an international scale (Forbes; James Conca, 2020). Furthermore, due to the extensive range of payloads and attachments drones can carry, there is potential for drones to have multiple uses in the field of environmental management, including filling in gaps of data collection that satellites remote sensing and aircraft are unable to obtain (Banu, et al., 2016). This is the mission of numerous companies around the world - to combat the long list of consequences which are attributed to deforestation and climate change.

2.2 The application of drones in reforestation

The processes and practises of the numerous companies involved in ecological rehabilitation through drone technology differ slightly, though each share the same basic concepts. As an example of how these companies operate, Dendra System's approach will be examined. Dendra Systems (formally Biocarbon Engineering) aims to works with Fortune 500 companies, Private Landowners, Intergovernmental Agencies, and Governments to create scalable rehabilitation and restoration to land in need (Fletcher, 2018). Recently, Dendra Systems received £10M in investments to expand the business, enabling them to take on more projects for regulated industries which contribute to land degradation, or companies with an economic incentive for ecological restoration (Graham, 2020).

Based in the UK, Dendra Systems have undertaken projects on an international scale, specialising in analytics, data ecology, and aerial seeding. The organisation is comprised of four primary fields of expertise working together to produce the sci-fi like method of planting trees and other flora:

- Ecologists – through research and fieldwork, ecologists ensure that the seed pods planted by the drones are up to the task; as well as ensuring that the chosen seeds are suitable for each site which is being rehabilitated. Dendra Systems is involved in projects internationally. Hence why factors such as landscapes, weather conditions, soil types, and local species differ greatly, therefore the correct choice of seeds to plant is imperative to the success of rehabilitation of the land.
- Software and Artificial Intelligence Engineers – this department generates the software needed for surveying and seeding of the rehabilitation projects. In addition, the software engineers scale up the results from ecologists with regard to the survey data, creating a tailor-made pattern of seeding for each specific site.
- Drone Operators – a self-explanatory title, this department is trained to transports, operate, and handle the drones used for rehabilitation and aerial seeding on the site of the project. Through drone operation, these professionals are responsible for the collection of data needed for the ecologists and software engineers. Once the ecologists and software engineers have utilised and scaled up the data, aerial seeding can be carried out by the drone operators.
- Hardware Engineers – the professionals who design, customize, and modify the hardware of the drones, and the hardware which enables the on-site data collection and aerial seeding (Dendra Systems (1), 2020).

Figure 2- Example of drone used by 'Flash Forest' during planting process (Forbes; James Conca, 2020)

Ex-NASA engineer and founder of Dendra Systems Lauren Fletcher gives a simple explanation to how the concept of drone reforestation takes place during a speech at 'Unreasonable Impact' in 2017 – "First we take detailed images of the trees, topology, the nutrients, the biodiversity, and we crunch that information through a machine learning algorithm that allows us to produce a precise planting pattern. Next, we upload this into our planting drones; these fly at 2-3m above the ground and fire a small biodegradable seed pod at each of the predetermined positions. These penetrate the ground, are activated by moisture, and contain all the nutrients necessary for healthy tree growth. Two operators running a small swarm of drones will have the capacity to plant 100,000 trees a day" (Lauren Fletcher, 2017). The method of direct seeding is not a new concept, seeding by hand has been used in reforestation for many years, and the use of helicopters to spread seeds was introduced as early on as 1962 (Canadian Silviculture, 2005). However, the use of drones for the purpose of direct seeding was almost unheard of before 2017, allowing for this technological innovation to bring an array of new benefits to reforestation and conservation efforts.

Typically, the drones used for this purpose of aerial seeding are composed of three primary components: a custom-built quadcopter, a computer controlled seed dispenser, and software which can construct a 3D model of a specified area, enabling precise GPS coordinate targets on the ground to fire seed pods. The act of aerial seeding is achieved by first surveying a specified area for factors relating to soil condition, allowing for the best suited species of tree to be planted. The planting itself is achieved through modified seed pods - comprised of biodegradable materials. Pods contain the seed and sufficient nutrients to aid in growth after germination; giving the saplings a fighting chance to establish roots and one day become mature trees.

Dendra Systems carried out initial tests in the UK to test survival rates of the seeds, using different species. Results showed that the survival rate was similar to the use of helicopters to spread seeds – however the use of drones for this purpose has greater benefits attached to it such as precision and monitoring post sowing. Testing results also presented similar survival rates for some species compared to hand planted survival rates (Stone, 2017). The survival rate for direct seeding operations is around 19-24% due to the chance of germination, feasibility of the topsoil for the seedling after germination, animal predation in both seed and seedling stages. However, this low percentage is offset through multiple seeds being stored inside a seed pod to improve chances of survival. Further research has been conducted on the variance between aerial seeding being carried out from different heights. Results showed that low-elevation aerial seeding was more successful than mid-elevation in establishing more seedlings (Writh & Pyke, 2011).

A notable early project of Dendra System's first projects took place in Myanmar, after the countries' already at-risk mangrove forests were devastated by extreme weather conditions exacerbated by climate change. Mangrove trees are especially important to the natural world, as they are the only forests to grow in salt water – providing even more benefits than in-land forests. These forests store around 5 times more C02 than those which reside in rainforests, with one mature tree producing enough oxygen for 4 people. With the world's oceans becoming more polluted, mangroves are also able to filter the salt water, helping to protect sea life, all while providing habitats within the roots. Furthermore, these forests benefit life on land by reducing shoreline erosion and improving life for those living near the coast (Worldview International Foundation, 2020).

The Worldview International Foundation began a campaign in 2012 aiming to plant 1 billion mangrove trees in Myanmar, an admirable goal. In the first 7 years of the campaign, voluntary labour from two Myanmar universities had planted over 6 million mangrove seedlings through traditional reforestation methods (Tarantola, 2020). Although this effort will impact the ecosystem and local communities greatly, it falls short of the 1 billion goal. Due to the slow process, the Myanmar government contracted Dendra Systems to rehabilitate an area of over 250 ha in 2018. Since that time, the mangrove saplings have grown to 20 inches tall; providing a success story for the aerial seeding method of rehabilitation. If significant contributors to reforestation and C02 emissions were to adopt the common practise of utilising drone technology, the goal of 1 billion trees may be easier to achieve.

2.3 Companies Pioneering drones for environmental management

As discussed, Dendra Systems is one of the main organisations which utilise drone technology for ecological rehabilitation, though there are numerous other companies with similar operations around the world.

Flash forest "is Canada's first-to-market and largest drone reforestation company that uses UAV hardware, aerial mapping software, automation, and biological seed-pod technology to reforest areas at a rapid pace" (Flash Forest, 2021). The companies starting goals were to aid in the offset of C02 emissions to the extent where it could be quantified and allow people to get involved in reforestation,

Lord of the Trees claim to be a revolution in tree planting. "Lord of the Trees is developing fully autonomous pre-programmed drones that will work day and night to replant deforested areas around the world. Working with the mining sector, local governments, the agricultural industry, and landowners, we can help accelerate reforestation efforts and achieve planting on a mass scale at a significantly reduced cost" (Lord Of The Trees, 2020). This company completed 2 projects so far, one in Western Australia and the other in Sumatra. Similar to Dendra Systems, Lord of the trees work with governments, local authorities, Non-Government Organisations (NGOs), farmers, and industrial organisations. The story of how the idea for this company was born involves the life-long environmentalist, David Attenborough. During an Attenborough documentary on the Galapagos island, it was revealed that a previously barren island was now covered in rainforest flora and fauna due to the nature's own drones, birds. With seeds surviving through their digestive system, birds inadvertently reforested an island. Through biomimicry, the concept of Lord of the Tree's unique drone technology was developed – allowing them to plant 288,000 seeds in only 12 hours (Lord of the Trees, 2021)

Land Life Company state that "Our continuous cycle of R&D ensures scale, efficiency and transparency when innovating tree planting and forest management. By strategically applying tailored technologies and the data it produces, we apply scientific and computing expertise to grow trees as efficiently and transparently as possible" (Land Life Company, 2020). An organisation which employs a high-tech holistic approach to ecological rehabilitation, Land Life Company uses a variety of methods and technologies to achieve their goals of planting trees and capturing C02. To date, they have planted 2,669,669 trees which equates to 2,899 hectares of land being rehabilitated – resulting in 594,928 tonnes of C02 removed from the atmosphere. This has been achieved through the use of drones as well as specialised machines to plant trees mechanically. After the trees reach a height of one meter, drones are used for monitoring to ensure growth and survival. When the tree is over 5 years old and is clearly visible from the sky, monitoring is transferred to satellite imaging technology. Throughout this monitoring, the data is fed into the company's database where further analysis can take place (Land Life Company, 2021).

2.4 Forest Wildfire Restoration

As a by-product of climate change, extreme weather is becoming more prevalent across the globe. This puts significant stress on the flora and fauna of countless habitats across all continents. Perhaps the most destructive of these weather changes derive from the wildfires created by longer, drier summers, and increased temperatures. This ever-growing threat burned over 2.7 million ha in the West Coast of the United States alone, which contributed to 30 deaths and the displacement of thousands of residents (Xu, et al., 2020). This was but one of the many wildfires in 2020, with the EU estimating that around 67 million ha of forest burn each year (European Commission, 2019).

Notably, wildfires are naturally a semi-regular occurrence, forests are capable of regenerating – sometimes being even advantageous to the ecosystem. However, there is evidence to show that due to the changing climate and an increased occurrence of these wildfires, forests are becoming less resilient. The regeneration rate of trees after wildfire is a primary indicator of the resilience of a forest. This regeneration has been shown to have decreased in the 21st century due to higher moisture deficits and lower densities of seedlings/seed dispersal (Stevens-Rumann, et al., 2017). If the resilience of forests is declining while the frequency/severity of wildfires continues to rise, coupled with human deforestation, direct intervention is needed on land ravaged by wildfire.

The intervention needed to mitigate the damage of wildfires could potentially be achieved with the aid of drone technology. DroneSeed is another example of a company which utilises drones for ecological rehabilitation. Specifically, this company specialise in regenerating areas which have been affected by wildfires. Part of the reason for this specialisation is that post wildfire, all the weeds or plants that would shade a newly planted tree are gone, and so there is an increased chance for the new trees to grow. Based in Seattle, USA; DroneSeed claim to plant seeds six times faster than a human is capable of doing, and propagate around 40 acres (16 ha) a day, as rapidly as 30 days after the wildfires have taken place (Droneseed (1), 2020). The company also offers a “free wildfire assessment for landowners with 50+ acres”.

This ‘wildfire kit’ includes satellite images of the land from before and after the wildfire took place, with a further satellite image every 2 weeks of the regeneration of the site (Droneseed (2), 2020). The satellite images provided also include an analysis as to the extent of the fire damage, an important aspect for the planning stages of restoring the areas affected. This analysis includes:

- A percentage value of the trees which have been lost to the wildfire, calculated through the estimation of trees in the satellite images before and after the wildfire, including a rough time scale of when invasive species may take hold in the deforested land.
- The estimation of tree loss is followed up by a further assessment of the areas which have burned and are now susceptible to invasive species of trees or other vegetation.
- The species of trees on the land prior to the wildfire are identified, quantified, and displayed as percentages. This helps ensure the balance of native tree species is maintained if rehabilitation takes place. However, this species identification is conducted using the mid resolution satellite images and will not be as accurate as the use of a surveying drone. Drones

are ecologically programmed in identifying and quantifying tree and plant species with higher resolution imagery. (Droneseed (3), 2020)

The rest of the analysis provides information on the processes and practises of DroneSeed to educate the potential client. This includes a cost comparison of the traditional method of reforestation. DroneSeed place the cost of rehabilitation per acre (which is 0.4 ha) at $530 – 677 in the US. This traditional method price includes the off-site growing of the trees, the labour and transport of the saplings/seedlings. This price also includes the removal of weeds; due to the longer waiting period of rehabilitation with traditional methods, invasive species have often already started to take over (Droneseed (3), 2020).

DroneSeed price their regular services at $300-500 per 0.4 ha; with cost reductions deriving from the avoidance of weeds, as aerial seeding is conducted within 30-90 days and the avoidance of extensive manual labour. The company offers a further reduction in cost through their 'DroneSeed Carbon' option, giving access to discounted carbon rates and costing $200 – 300 per 0.4 ha. This is achieved through the carbon credit initiative, allowing companies who contribute to C02 emissions offset their carbon footprint through paying to have the client's land reforested (Droneseed (3), 2020).

DroneSeed uses drones which are 8 feet in diameter with 6 rotors, capable of carrying a payload of up to 25kg of seed pods – with a flight time total of 18 minutes. The seed pods (or seed pucks) that DroneSeed use are specifically designed to survive in a post wildfire landscape. These pods are comprised of a vessel which is made of dry fibres that soak up any moisture and retain it, while the internal fertiliser aids in seed growth and natural pest deterrents such as spicy pepper are used to avoid predation of the seeds. The evolution of these seed pods is displayed in figure 2. Numerous test phases were undertaken to improve both the seed survival rate, and likelihood that the germinated seed establishes well to become a mature tree in the future.

Seed vessel version (year deployed)	Design features and amendments
"Beta" - Version 1 (2018)	Fiber-based pellet Single-sided seed configuration pH stabilized
"V2" - Version 2 (2018)	Fiber-based pellet Double-sided configuration pH stabilized
"V3" - Version 3 (2019)	Fiber-based pellet Double-sided configuration pH stabilized Olfactory and gustatory predatory deterrents (plant-based)
"V4" - Version 4 (2019)	Fiber-based pellet Double-sided configuration pH stabilized Olfactory and gustatory predatory deterrents (plant-based) Pathogen risk mitigation
"V5" - Version 5 (2020)	Advanced materials for fiber-based pellet (2 varieties) Double-sided configuration pH stabilized Olfactory and gustatory predatory deterrents (plant-based) Enhanced manufacturing process for amendments/seed Nutrients and beneficial organisms (optional) Biochar and other carbon or mineral material supplements (optional)

Figure 3 - Display of the DroneSeed seed 'puck' through various stages of design evolution through 2 years of testing (Aghai & Manteuffel-Ross, 2020).

2.5 Ecological Restoration on dangerous or degraded land

Land which requires rehabilitation is frequently located in areas which have been heavily affected by industries such as mining. This often renders the land fraught with health and safety hazards; leaving behind terrain which may be difficult to navigate, and possibly detrimental for the people employed to provide ecological rehabilitation. Vertical shafts left by mining activities can be left poorly secured and covered by vegetation, presenting a potentially fatal fall risk. Similarly, horizontal mine shafts which are stabilised by old (possibly rotting) timber, coupled with potentially unstable rock formations make cave-ins and sink holes a very present danger in these landscapes shaped by mining (Wyoming Department of Environmental Quality, 2018).

Western Australia's heritage involves significant levels of mining, to the extent where the local government has issued pamphlets educating people to the dangers associated with abandoned mining land. Much of this mining activity was open cast. This form of mining leaves behind large quarries with unstable "highwalls" (essentially man-made cliffs), potentially hazardous waste, abandoned structures or equipment which may be unsafe, and even forgotten explosives (Government of Western Australia Department of Mines, Industry Regulation and Safety, 2017). Most developed countries have land which was historically used for mining and other heavy industry during times of industrial revolution, now abandoned and left in unsafe conditions. The use of drones to rehabilitate this type of land circumvents the health and safety risks involved with manually planting seeds/seedlings on the ground via more traditional means.

This very situation was encountered in 2019 for a project undertaken by Dendra Systems in Australia. As organisations in developed countries are now held to higher standards compared with previous historical industrial activities, Environmental Management Systems obligate industrial sites to be remediated rather than simply and haphazardly abandoned. As part of its Environmental Management System, Glencore - the largest mining company in Australia - contracted Dendra Systems to aid in the restoration of land disturbed through the companies open cast mining activities (operated by Bulga Coal), situated north of Sydney. Due to the difficult terrain on site, the traditional methods of planting were made more challenging and posed a risk to health and safety. Instead of risking safety, the solution was to utilise drone technology for aerial seeding. Bulga Coal's environmental team stated that they "wanted to incorporate automated aerial seeding into its rehabilitation program to address 3 primary needs: Enable access to challenging environments; improved site safety; and reduce erosion risk." (Bulga Coal; Dendra Systems, 2019).

Dendra System's SKAI Scan™ was used to survey the land in need of remediation prior to seeding, mapping it out and allowing plans to be made for species choice as well as the best seeding patterns. After scanning, SKAI Tractor™ was operated to sow a mix of seeds native to local woodland, and a mix of seeds of native pastures, which were seeded on the more contoured slopes of the land which may not have been stable enough to support a growing tree. Finally, post-rain monitoring was undertaken to evaluate the germination of the seeds. This case study saw multiple benefits from the use of drone aerial seeding capabilities. As Bulga Coal were previously using tractors to navigate and rehabilitate the land, less soil disturbance and compaction took place, and less time was spent on the project due to the drone's speed and a lack of tractor breakdown/repair. SKAI Scan™ and SKAI Tractor™ allow for the seeding operations to be geo-tagged which aids and assists in monitoring the success of the seeds. Finally, as mentioned above, the health and safety risks involved were decreased significantly, which benefits both the company and its employees (Bulga Coal; Dendra Systems, 2019).

Companies such as Glencore and Bulga Coal which adhere to environmental policy can make useful tools of drones in achieving aspects of their Corporate Social Responsibility. However, there exist companies/countries who do not hold environmental protection in high regard; and instead, favour to pillage the earth's natural resources in an unsustainable manner for monetary profit - either through illegal activity or poor environmental regulations (Carrington, et al., 2018). It is only fair that these countries have the right to prosper through their natural resources like most developed countries have done in the past. Though with scientific innovation in recent years, it is possible for the damage industrial activity inflicts on the environment to be accurately quantified; and it is not wise to repeat the mistakes of the past. A significant percentage of tree cover which is lost every year takes place in developing countries, specifically tropical regions. In 2019 alone, 11.9 million ha of tropical forest was lost. Almost a third of this loss was situated in mature rainforest areas, imperative to biodiversity and carbon capture/storage (Global Forest Watch, 2020).

A common victim to illegal deforestation is the Amazon Rainforest, often aptly referred to as the "Earth's lungs". Shared by 9 countries and spanning over 800 million ha, it is a vast area, with conservation being a difficult task (Yale School Of The Environment, 2021). However, with the increasing use of drone technology, environmental conservationists have been given a new tool to combat the destruction of these important forests. Madre de Dios, an area of the Amazon Rainforest in Peru has suffered vast deforestation and degradation through the activities of gold mining (Espejo, et al., 2018). The use of a "DJI-Phantom 4" drone and "DroneDeploy" automated flight software provided the solution to view this degradation clearly from the sky. This method enabled the categorisation of the different substrate types, the extent of the destruction caused over 40 ha of land and supplied data to influence the planning stages of ecological restoration, all while saving the team both financially and in time spent on the project (Pillaca, et al., 2017). Although this restoration project did not involve the use of aerial seeding from drones, it demonstrates how useful the technology can be in the surveying and planning stages of restoration or conservation projects.

3. Analysis of suitability for drone use in Ecological Restoration

A reasonably new technology, such as drones, being capable of solving significant environmental issues which have plagued the Earth for so many years, may appear to be too good to be true. This is why further examination of the results from this method must be applied to this dissertation. In order to analyse if the use of drones should become a commonly applied solution for deforestation, numerous aspects must be considered to gain an accurate representation of the possible advantages or disadvantages that drones present. This methodology will attempt to:

- Understand the inherent differences between drone aerial seeding (direct seeding) and traditional nursery saplings planted by hand.
- Provide information on the material and financial inputs needed for drones to function effectively in reforestation efforts.
- Investigate the potential for reforestation intervention using drones to mitigate climate change and ecological rehabilitation.

3.1 Direct seeding compared with traditional methods

Multiple factors need to be explored to understand the differences between the use of drone technology to restore ecology and that of the traditional methods. This analysis will include the differences in resultant growth from direct seeding compared to the planting of nursery saplings, and the success rates of aerial seeding.

There are two distinct methods for growing trees. The first method which is most commonly used in reforestation projects around the world is transplanting. This involves the use of a nursery to grow seedlings or saplings to a certain stage of maturity, before transplanting them in the ground where they can further integrate themselves and grow stronger. Direct seeding is performed by simply planting a seed in the ground and allowing nature to do the rest. There is a third option, though it does not involve human intervention. This option resolves to allow nature to reclaim the deforested area through natural regeneration. This is a viable method, though with current deforestation rates it would result in ecological disaster. The supposed benefits of direct seeding include:

- Reduction in financial cost and time
- Increased availability of seeds compared with nursery seedlings/saplings
- Easier for any labour involved in the process
- Direct seeding can be done at anytime of year, given adequate soil moisture is available
- Circumvents possible transplant shock to the seedlings/saplings
- This method is more natural, allowing for natural root growth (Natural Resources Conservation Service, 2009).

While direct seeding has been a popular method in history, due to the increase in developed countries involvement in reforestation, the more expensive and time-consuming method of transplanting became the norm in reforestation efforts. However, due to the growing size of the global climate problem and the continuation of mass reforestation, the simpler method of direct seeding is being reconsidered. A contributing factor to why direct seeding fell out of use, was due to reforestation programmes/plantation forestry requiring sites to be stocked with a certain quantity of trees compared to the planted area; something direct seeding cannot guarantee (Grossnickle & Ivetic, 2017). Direct seeding by hand and direct seeding by drone may sound worlds apart, though the result is much the same – with the difference of drone seeding supplying the seed with extra protection and fertilisation. Considering this, results from both drone aerial seeding and traditional direct seeding were examined for results.

The root systems which develop as a result of direct seeding are considered natural, and the root systems grown in nurseries and then transplanted can become distorted, especially if the hole that the tree is planted in is not big enough. A root system which becomes distorted inhibits the growth of the tree, reducing the survival rate – showing positive growth in early stages of life but not allowing the tree to reach full maturity. Although direct seeding requires a significant amount of ecological knowledge, around 80 percent of direct seeding operations are considered a success, as long as proper procedures are followed (Kushla & Ezell, 2019). It is difficult to calculate a mean average of the survival rate of seeds in direct seeding operations, though from research across multiple experiments a range of between 15-25% would be accurate (Di Sacco, et al., 2020). This, however, can be offset through the planting of additional seeds to offset potential for loss through seeds not germinating, animal predation, and insufficient nutrients from topsoil.

In comparison, through the method of transplanting, trees in agroforestry have a mean survival rate of 51% in cases of trees that are on private land. This is due to the trees being regularly maintained and monitored to limit any possible damage from pests or weather. Additionally, trees on private land will most likely receive frequent care though pruning, weeding, watering during times of drought, fertilisers, and mulching (topsoil such as bark to retain moisture). Furthermore, the operations on private land are more likely to involve experts, ensuring that the operations are conducted adequately. This survival rate for transplanted trees in agroforestry drops to 30% when on public land, due to less care being given to the trees. Forest plantations and woodlots result see even higher survival rates, at 40% and 65% respectively (Munyanziza, et al., 2013).

There is a possibility for a margin of error in both the results of direct seeding and transplanting due to the countless factors which effect germination and tree growth. Some species of tree fare better through direct seeding and left to grow with no fertiliser added, other species prosper through being transplanted and being given liquid fertiliser and mulch over the topsoil (Engel & Parrotta, 2000). Understanding the needs of different species is imperative, as time and money will be lost if a species of tree seed is spread and planted when that tree fares better through transplanting. Drone technology being introduced to reforestation does not and should not phase out traditional methods, even if aerial seeding proves to be effective – there will always be species of tree and plant life which requires different treatment.

The primary disadvantage of traditional direct seeding derives from the inability to accurately control the placement and stocking of the tree, as the number of seeds spread is based on projected survival rates. However the opposite situation can occur, when seed germination and survival rate is not adequate due to outside circumstances (e.g. drought, animal predation) (Kushla & Ezell, 2019). This disadvantage can be corrected with the use of drone technologies ability to geo-tag and monitor the growth of trees, limiting spacing errors and being able to correct them if they do occur. Furthermore, the predation of seeds can be mitigated through new methods of seed coated barriers. The active ingredient (Capsicum) in chili peppers which makes them spicy has been utilised as a deterrent for seed and grain foraging mammals who have the potential to limit the effect of reforestation efforts through direct seeding. This method has proved to be a success and is used in the seed pod capsules dropped by DroneSeed aerial seeding (Pearson, et al., 2019).

Although minimal, some data collection has been conducted on the results of drone aerial seeding. During the testing phases of DroneSeed's seed pucks, research was conducted in New Zealand over 16 separate sites. This research was to determine both ecological data on different species preferences, though the primary goal was to establish seed to seedling ratios. The data results in figure 4 show that each species showed varied establishment ratios ranging from 0.4 to 37.5%. The average establishment for each species are as follows:

- Douglas-fir – 1.6 %
- Radiata pine – 5.4%
- Manuka – 16.3 % (Aghai & Manteuffel-Ross, 2020)

Observations from the research on-site concluded that the microsites where seeds were planted prove to correlate strongly to the chance of seed germination. Microsites are small-scale areas where seeds may receive more suitable conditions from the environment; for example, partial shade from surrounding vegetation or recesses in the ground where predation is less likely. It is important to note that predation deterrent chemicals (Capsicum coating) were not used on these seeds, so the additional advantage of that method is not included within the results (Aghai & Manteuffel-Ross, 2020).

Species	Seed treatments	Sample size[1]	Number of plots	Site types	Seed to seedling ratio (percent established)	Percent of pucks with seedling establishment	Trees per acre[2]
Radiata pine	Stratified or dormant	500 to 1075	8	Cutover	0.1 to 3.7	0.4 to 14.8	3 to 159
Douglas-fir	Stratified or dormant	400	4	Pasture rehabilitation and cutover	0.1 to 1.1	0.5 to 4.3	2 to 17
Mānuka	N/A	550 to 565	4	Earthquake restoration	0.1 to 3.8	0.5 to 37.5	3 to 212

[1]Range of puck quantities per plot; mānuka was amended with approximately 10 seeds/puck; Douglas-fir and radiata pine were amended with 4 seeds/puck.
[2]Estimated established, per plot.

Figure 4 - Variety of results from one of the later versions of DroneSeed's seed pucks from research conducted on 16 separate plots of land. Puck aerially seeded in August and data collected November 2019 (Aghai & Manteuffel-Ross, 2020).

An important aspect of any project; cost determines the scale and quality of reforestation projects, especially in countries which have limited resources to tackle deforestation and climate change. Figure 5 contains a detailed breakdown of the differences in cost between direct seeding and other forms of planting; including manual, mechanical, and barefoot. The results showed that direct seeding cost between 30% and 38% less compared to bareroot and nursery grown seedlings. This is in part due to the cost of the seeds themselves – not all tree species are easily obtainable, especially with high rates of deforestation and great demand for reforestation. With regard to nursery grown seedlings alone, direct seeding is 29 times more economical (Grossnickle & Ivetic, 2017). However as demonstrated previously, direct seeding results in lower establishment rates compared to nursery grown stock, so this must also be considered in the planning stages of a reforestation project. The lower establishment rate of direct seeding allows for the possibility of a project costing more than other methods if the type of seeds required are expensive – an increase number of seeds would be essential to ensure the correct quantity of saplings are germinated and matured. This demonstrates that a holistic approach is necessary in the planning stages of reforestation costs. Cost of method should be considered as well as species selection, site topsoil condition, likelihood of predation, and potential for failure/requirement for re-seeding.

Species	**Prices ha^{-1}**					**RATIO[3]**			**SOURCE**
		Container							
	Direct Seeding	Manual	Mechanical	Bareroot [1]	**Currency[2]**	DS/CON Man	DS/CON Mech	DS/BR	
Multiple species in Australia	1,121	6,913	5,420		AUS	16%	21%		Summers et al. 2015
Pinus contorta	365			1,280	CAN			28%	Caldicott 1989 (converted to 2500 seedlings per ha)
Pinus contorta	249			772	US			32%	Sullivan and Sullivan 1984
Pseudotsuga menziesii	303			772	US			39%	
Pinus sylvestris	450	1,000			Euro	45%			Helenius 2016
Quercus robur	1,375			3,000	Euro			46%	Madsen and Löf 2005
Quercus sp.	845	1,200			Euro	70%			González-Rodríguez et al. 2011
Betula sp.	245			1,415	UK			17%	Willoughby et al. 2007
Five species in Costa Rica	351			3,737	AUS			9%	Cole et al. 2011 (converted to 2500 seedlings per ha)
Five species in Brasil	830			1,850	US			45%	Engel and Parrotta 2001
New Zealand native species	9,610			18,745	NZ			51%	Douglas et al. 2007
Quercus sp.	64			150	US			42%	Bullard et al. 1992
Fagus sylvatica and *Abies alba*	900			6,600	US			14%	Baumhauer et al. 2005
Fagus sylvatica	700			3,750	Euro			19%	Madsen et al. 2006
Fagus sylvatica	2,000			7,000	Euro			28%	Birkedal et al. 2006
Pinus kesiya	339			2,050	PhP			16%	Noble 1985
Pinus banksiana	210	717			US	29%			Adams et al. 2005
Picea mariana	216	780			US	28%			Adams et al. 2005
AVERAGE RATIO						**38%**	**21%**	**30%**	

1) Stocktype trial information was defined as bareroot seedlings when there was clear definition of stocktype type.
2) Currency: Australian dollar (AUS), United States dollar (US), Canadian dollar (CAN), Euro (EU), United Kingdom pound (UK), New Zealand dollar (NZ)
3) DS – direct seeding, Cman – manual planting of container seedlings, Cmech – mechanized planting of container seedlings.

Figure 5 - Comparison of cost between direct seeding and planting nursery grown seedlings derived from multiple reforestation projects. Cost comparison calculated for a density of 2,500 seedlings ha^{-1} (Grossnickle & Ivetic, 2017).

Data involving the cost of ecological rehabilitation with drone technology was very limited. This prompted the use of the DroneSeed service estimates (Droneseed (3), 2020). Using this data, a table (figure 6) was created to showcase the difference in cost between the three different options that DroneSeed offer. These three options were listed as costing:

- Traditional methods - $ 530 - 677
- DroneSeed standard prices - $ 300 - 500
- DroneSeed with carbon credits initiative - $ 200 - 300

The data table was constructed with the presumption that all three options would be the maximum of the price estimate. Per 0.4 hectare (1 acre), the price difference would be significant to a private landowner with little financial resources. It costs $177 more to regenerate lost forest through traditional methods compared to the DroneSeed's basic service package. With the additional financial bonus of utilisation carbon credit funding from companies, governments or other bodies who aim to reduce their carbon footprint, traditional methods cost $377 more. These figures were calculated to get an understanding as to the cost of using drones for massive international reforestation. This scale was increased to an extent of 1 billion ha, as it has been shown that a possible 0.9 billion ha is viable with regard to current land use (Finegold, et al., 2019).

Within the 1 billion ha projection, traditional methods of reforestation would require a grand total of $169,250,000,0000. Comparing this to standard DroneSeed prices, the difference would equate to $442,500,000,000. Furthermore, savings from the use of carbon credits and drone technology would be $942,500,000,000. Although a theoretical viewpoint of the differences in price between traditional methods and drone technology and not a recommendation for this extent of use, the potential savings for less large-scale reforestation is significant.

	Ecological restoration price per service ($)		
	Traditional methods	DroneSeed	DroneSeed Carbon
Max. price per 0.4 ha ($)	677	500	300
Area (ha)			
1	1692.5	1250	750
10	16925	12500	7500
25	42312.5	31250	18750
50	84625	62500	37500
100	169250	125000	75000
200	338500	250000	150000
500	846250	625000	375000
1000	1692500	1250000	750000
5000	8462500	6250000	3750000
10000	16925000	12500000	7500000
15000	25387500	18750000	11250000
100000	169250000	125000000	75000000
150000	253875000	187500000	112500000
1000000	1692500000	1250000000	750000000
1500000	2538750000	1875000000	1125000000
25000000	42312500000	31250000000	18750000000
50000000	84625000000	62500000000	37500000000
75000000	1.26938E+11	93750000000	56250000000
100000000	1.6925E+11	1.25E+11	75000000000
500000000	8.4625E+11	6.25E+11	3.75E+11
1000000000	1.6925E+12	1.25E+12	7.5E+11

Figure 6 - DroneSeed price data scaled up to produce possible price projections of global ecological restoration using drone technology (Droneseed (3), 2020)

3.2 Drone material and energy input

When drones are manufactured, every aspect of the design and material used is considered for optimal efficiency. For every gram of material used in a drones manufacturing costs energy to lift it off the ground – so every gram saved through the use of lightweight materials improves performance and functionality. Primarily drones and comprised of 4 different materials which include (Lanning, 2019):

- Carbon fibre-reinforced composites (CRFCs) – used for its light weight, the production of virgin carbon fibre is energy intensive, though re-use and recycling is possible. The environmental impacts of recycling are relatively low for CRFCs, though it can depend on the individual design criteria's of the components (Meng, 2017).
- Thermoplastics (e.g. nylon, polyester, polystyrene) – making up around 80% of plastic which is produced. Current recycling capabilities ensure that a significant number of produced thermoplastics are recyclable, reducing its impact to the waste cycle (Garrain, et al., 2007). Though plastic production is not often encouraged by environmentalists, it is a necessity in some cases for design purposes. Without the use of lightweight plastics for drones, the capabilities of the drone would be hindered; for example, flight time and top speed.
- Aluminium – in 2012, aluminium production contributed 861Mtonnes of C02 equivalent. However, the processes and practises of production differ from country to country. China produces 46% of aluminium, where the refining processes have a higher than average energy intensity. This most likely contributes a significant amount of C02 to the total emitted through aluminium production. The use of aluminium does make drone manufacturing less sustainable, though aluminium is a very common metal used in greater quantities in other essential products; so this may be an unavoidable environmental impact (Paraskevas, et al., 2016). Although aluminium is one of the lightest metals, it is not light compared to the plastic components. Therefore, a minority of the materials will consist of aluminium. See figure 7 for

a depiction of the outer body of a quadcopter drone, most of which is carbon fibre and thermoplastics.

- Lithium Ion batteries – From the market analysis of available commercial drones shown in figure 8, it is clear all drones utilise these batteries. There are significant environmental issues with the production of these batteries. The extraction of the around 20 different materials needed to manufacture a lithium ion battery hold multiple environmental and social/health issues, including child labour in some mines. After material extraction, the refining process necessary to make the batteries is energy intensive, further adding to environmental impacts. Due to the extensive manufacturing necessary/different methods used to make lithium ion batteries, it is difficult to quantify the exact environmental impact as results are different – though it ranges from 39 kg C02e/kWh to 196 kg C02e/kWh. However the increase in this type of battery manufacturing is not due to the rising popularity of drones; it is primarily the transition towards electric vehicles (Melin, 2019).

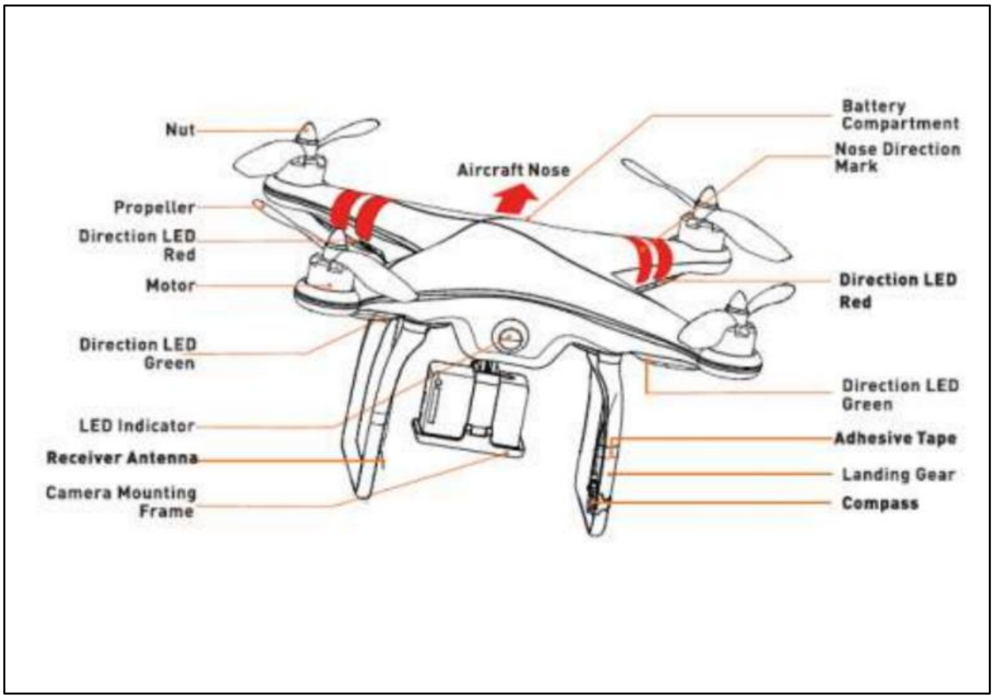

Figure 7- Diagram of a quadcopter drone, indicating each component of the complex technology (SYST 460, 2019).

The majority of materials necessary to manufacture drones are not considered to be sustainable, though they are necessary all the same due to the need for lightweight, robust components. This does diminish the positive environmental aspects of drone manufacturing. However, it is what drones can be used for which offers positive environmental impacts. The need for these types of materials will not increase or decline by a significant amount if the production of drones were to halt.

Drone Type	Flight time (minute)	Weight (g)	Operating Range (km)	Top speed (m/s)	Photo Quality (Megapixel)	Video Quality	Cost (£)	Rotors	Battery type	Voltage (V)	Energy (Wh)	Capacity (mAh)
DJI Mavic 2 Pro	31	907	5	20	20	4K	1819	4	LiPo 3S	11.4	43.6	3830
DJI Phantom 4 RTK Drone	30	1391	5	16	20	4K	5345	4	LiPo 4S	15.2	89.2	4920
Parrot Anafi Work Drone	25	320	4	14	21	4K	1078	4	Lithium polymer	7.6	N/A	2700
DJI M300 RTK	55	6300	8	23	N/A	N/A	N/A	4	LiPo 12S	52.8	274	5935
DJI Matrice 210 V2 RTK	34	4910	5	22	N/A	N/A	N/A	4	LiPo 6S	22.8	174.6	7660
DJI Inspire 2	27	3500	13	22	20	4K	3058	4	LiPo 6S	22.8	97.58	4280
PowerVision PowerEye	30	3950	4	18	12	4K	2899	4	LiPo	22.2	99.9 x2	9000
Yuneec H520	28	1633	1.6	N/A	N/A	N/A	1399	6	Lithium polymer	15.2	79.8	5250
DJI P4 Multispectral RTK	27	1487	5	14	2	N/A	5750	4	LiPo 4S	15.2	89.2	5870
SwellPro Splashdrone	23	2387	16	20	16	4K	1990	4	N/A	N/A	N/A	5200
Freefly Alta 8	35	18100	3.2	N/A	N/A	N/A	17495	8	LiPo 6S	22.2	N/A	N/A
DJI Agras MG-1	24	10000	1	7	N/A	N/A	N/A	8	N/A	N/A	N/A	N/A
senseFly eBee Classic	50	690	3	25	20	N/A	N/A	1	N/A	N/A	N/A	N/A
Autel Evo II Series	40	1124	9	20	48	6K	1500	4	LiPo 3S	11.55	82	N/A
Skydio X2	35	775	3.5	16	45	4K	999	4	Lithium ion polymer	13.05	N/A	4280

Figure 8 - Data table of commercially available drones from developer specifications (references within bibliography).

An aspect to consider with the use of drones for reforestation is the energy needed to fly, operate, and re-charge the drones. Through the use of data in figure 8 a rough estimate of the drone energy usage can be calculated. This will be achieved through simply multiplying projected flight multiplied with the drone's energy (Wh) rating. Though the Yunnec H520 with 79.8 Wh is more commonly fitted with a camera payload, it would be viable to be fitted with seed dispensers due to the lift power of 6 rotors and reasonably light weight of 1633 grams. If used for a full day of aerial seeding, considering a flight time of 28 minutes and breaks for recharge time, the drone would fly for around 112 minutes. 112 minutes/60 = 1.87 hours. 1.87 x 79.8 = 148 W. The energy used does not outweigh the benefits to planting thousands of seeds in this time. From the market research conducted in figure 8, there is room for improvement in aspects such as flight time and operating range, however the technology is catching up with the purposes drones are now used for.

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3.3 Carbon capture potential of ecological restoration

Thus far, this dissertation has maintained that reforestation has the potential to mitigate climate change. This section will focus on the effect that reforestation has on C02. The common discussions involving the mitigation of climate change and C02 emissions primarily focus on topics such as improving/expanding renewable energy sources, the transition towards electric vehicles, reducing factory farming, and the further innovation of carbon capture and storage technologies. However, one of the simplest methods may be to use the natural environment to our advantage, with natural carbon sinks – by conserving existing carbon sinks and expanding them where possible. A natural carbon sink is any naturally occurring thing which can store carbon like forests, the ocean, soil, plant life, the air, and in all living things (National Geographic, 2021). The natural carbon cycle keeps the carbon in all these different places balanced; however due to human activity the balance has been slowly deteriorating over many years. One solution is to give back natures potential for storing carbon through reforestation, and many studies concur that it is a possible answer to climate problems (Ni, et al., 2016). The intriguing aspect of this solution is its simplicity, yet from the research conducted, it may actually be able to store enough carbon to make a significant and long-lasting difference.

One research paper set out to understand the C02 removal rates of different types of forest landscape restoration. These different categories of restored land include areas which have regenerated naturally, woodlots and planted forests, agroforestry, and mangrove restoration. The results show that within the first 20 years of growth, C02 removal rates ranged from 4.5 to 40.7 tonnes of C02 ha^{-1} year^{-1} for woodlots and planted forests and on average fared the best with regard to maximising growth. Second highest C02 removal rates were from mangrove restorations, at 23.1 tonnes C02 ha^{-1} year^{-1}. Lastly were natural regeneration and agroforestry respectfully, showings rates of 9.1-18.8 tonnes C02 ha^{-1} year^{-1} and 10.8-15.6 tonnes C02 ha^{-1} year^{-1} (Bernal, et al., 2018). There is research to determine that areas which regenerate naturally have significantly higher and stable C02 removal rates throughout growth, compared to areas which have been aerially seeded by drones. However, with the growth of the aerially seeded areas the C02 removal rates eventually caught up to be the same as that of the naturally regenerated areas.

There is currently over 0.9 billion ha of land which would be ecologically viable to grow forest cover – around 25% increase in forest area. This success in reforestation would result in a 205 gigatonnes of carbon being removed from the atmosphere and stored in newly restored natural carbon sinks. If this were to be achieved, atmospheric carbon in the atmosphere could be reduced by up to 25% and circumvent 20 years of human C02 emissions (from what C02 emissions currently are) (Finegold, et al., 2019). This would be a tremendous feat; though many believe this achievement would not be enough to mitigate climate change enough, and just play a partial role in the ultimate goal of halting climate change. Nonetheless reforestation is a worthwhile endeavour not just for carbon capture potential; but the multitude of other benefits that it brings.

3.4 Research limitations

Drones are a reasonably new technology, there are significant gaps in the research literature within the area that have yet to be explored. Moreover, this dissertation focuses on a specific application which drones can be used for; further limiting the available literature on the subject This reduces the scope for possible research applications and limits the likelihood to have opposing opinions within the dissertation to develop a well-rounded argument. Furthermore, a small spectrum of available research data limits the potential to compare results. Though all sources are credible, the trust in results through faith and not comparison or critique is not ideal. Additionally, it is important to be mindful that companies can use data in such a way to promotes the most sought after outcomes that benefits their own longevity.

The initial intention of this dissertation was to include numerous interviews with professionals from within the drone reforestation companies which were discussed within the review of existing literature. This would expand the scope of available data from credible sources, allowing for a more in-depth analysis of the potential of drones for ecological rehabilitation. Communication was extended through contacting companies via email as well as individual employees whose contact details were provided. Unfortunately lack of response from companies and professionals further limited available information on the dissertation. This prompted the expansion of analysis on drone reforestation capabilities from external sources which increases potential for drone capabilities to be inaccurately represented.

Conclusion and recommendations

The planet is currently experiencing the highest rates of atmospheric C02 in our known history. Every continent is experiencing climate change and loss of habitats due to natural balances becoming strained as a consequence of the industrious activities of humans. Reforestation has been put forward as a partial solution to these growing issues, and a majority of the available data says that this option is worthwhile. Action needs to be taken, though the slow processes of reforestation hinders further drives towards achieving significant enough levels of reforestation to properly tackle climate change.

Drone technology presents a crucial new tool to use in the world of reforestation – an innovation which can get people excited about an old and often overlooked practise which is not at the forefront of environmental movements. Moreover, the benefit of reduced costs for seeding may prove to be a significant driver for reforestation projects in developing countries with limited resources to combat habitat loss. However, drones used for aerial seeding do have limitations – primarily the survival rates of the direct/aerial seeding process. Given that direct seeding by hand also hold the same limitations, this ay not be an aspect which can be improved upon.

Therefore, this dissertation recommends that the drone reforestation is continued – allowing time for innovation in this niche market of drone technology. It is recommended that governmental bodies interested in reforestation efforts invest in this technology to further improve and integrate it into existing tradition methods.

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