The demand for tree planting: an over idealized quick-fix or a promising nature-based solution?

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Abstract

In recent decades, tree planting has gained momentum as a nature based solution to global challenges of climate change and to tackling the consequences of deforestation. Consequently, tree planting has been incorporated in policy and governance as a strategy to address these issues (e.g. EU Green Deal). Additionally, multinational corporations are also initiating or partnering with tree planting programs to improve their sustainability image and/or using the opportunity to gain or purchase carbon credits from the voluntary carbon market. A variety of studies indicate concerns where locations of non-forest terrestrial ecosystems have been proposed to upscale tree planting efforts. Therefore, this thesis seeks to answer to what extent current tree planting project sites adhere to sustainable practices and measures to ensure optimized net carbon sequestration, biodiversity conservation and local water management. Moreover, what recommendations of best practices should be made to ensure the sustainability of tree planting? This research study investigates these two key issues with a data inventory of 113 tree planting project sites associated with 20 different tree planting programs. Both qualitative and qualitative methods were used, involving a literature review and interviews. The programs were sampled through website links of multinational corporations, as well as through network connections when data was inaccessible or where time was a constraint. It was found that there were some misconceptions of key term definitions, where some projects labelled as “afforestation” were for the primary objective of forest restoration and additionally some projects labelled “reforestation” were found to be located within a non-forest terrestrial ecosystem. Furthermore, it was discovered that a majority of project sites did not monitor for local water management and this was also the case for biodiversity monitoring. Despite this, a large majority of the tree planting projects demonstrated to have mixed species planting, and most projects used solely native tree species. The results of this study have indicated the complexity of tree planting as a sustainable nature based solution, that it is very dependent on the project site, and that it involves a variety of different trade-offs. Nonetheless, this research has highlighted that there needs to be more biodiversity and local water management monitoring implemented for tree planting project sites, or at the very least, programs need to be more transparent about their project site measures and actions online.

Preface

The following thesis is presented, “the demand for tree planting: an over idealized quick-fix or a promising nature-based solution”. This thesis project has been composed to fulfil the graduation requirements of the degree Sustainable Development (MSc) at Utrecht University. Additionally, exploring a study on tree planting, with regards to its carbon sequestration potential may contribute to evaluate its effectiveness as a nature based solution/climate innovative strategy. Therefore, this thesis also adheres to the requirements of the Climate-KIC Master Label programme. The duration of the whole research project ran from February 2020 until the end of November 2020. My main research questions were formulated together with my university supervisor, Mariska te Beest. Mariska also provided me with valuable feedback on the structure of my thesis, enabling me to develop academically and focus on key areas of interest for my research project.

For this research project I undertook an internship position at WWF-NL where I had the opportunity to gain insights into the topic of tree planting. Furthermore, I was able to develop my expertise and knowledge into the topic with the excellent guidance of my WWF supervisor, Gijs Breukink. Therefore, I would like to give significant acknowledgements to both my supervisors for their extensive support throughout this process.

I would also like to thank the colleagues at WWF-NL and those who I interviewed for their time and collaboration. It was a pleasure to be part of the forest unit team. A special mention also to Manuela Van Vlasselaer as well as my partner and friends for all the help and encouragement they provided me. Finally, I would like to give an enormous thank you to my parents and brother for their consistent morale support and advice.

Contents

Introduction

In the previous decades there has been a growing global emergence of tree planting programs to mitigate the consequences of climate change, both stimulating momentum in the private and (non-)governmental sector (Mansourian et al., 2017; Lovell, 2010). An example of such a forest restoration initiative is the Bonn Challenge launched in 2011, for governments to commit to the global restoration of 350 million hectares of forest by 2030 through the funding of donors such as the World Bank (Bond et al., 2019). Global efforts by national governments are also further advancing the restoration of biodiversity, ecosystem services and forests (Chazdon, 2008).

A study conducted by Bastin et al. (2019) claimed that forest restoration is amongst the most effective strategies against tackling the issue of climate change. The study claimed that there is currently room for the global restoration of an extra 0.9 billion hectares of land for forestry (in addition to existing forestry) which could store 205 Gigatonnes of carbon (Figure 1). Studies such as Bastin et al. (2019) claim that there is significant potential for carbon sequestration and storage from tree planting sites. There is support for this notion and it has become an incentive for the expansion of carbon credit forestry market schemes, which has led to a lot of criticism. Nevertheless, support for this notion has increased the pressure on national and international political agendas to act and invest in tree planting projects in efforts to achieve targets such as the Bonn Challenge, Paris Agreement & the Sustainable Development Goals.

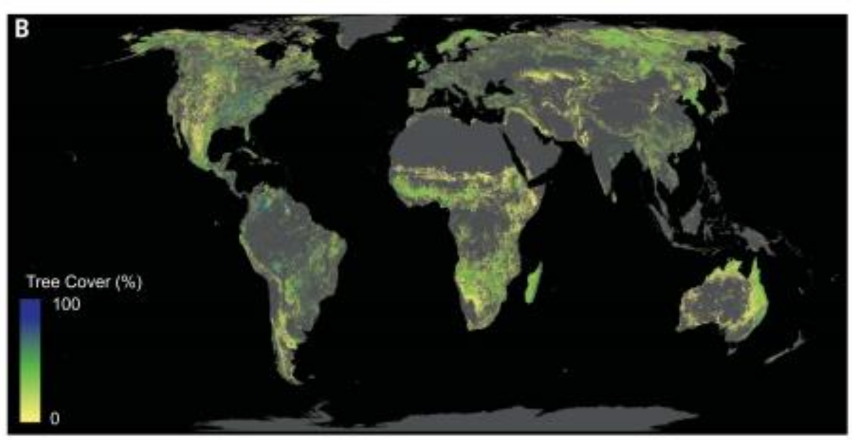

Figure 1. The potential tree restoration of the globe. This map demonstrates estimates for the potential area for tree cover restoration after subtracting urban and agricultural areas as well as the existing tree cover (Bastin et al. 2019). Reprinted from 'The global tree restoration potential' by J.F. Bastin, Y. Finegold, C. Garcia, D. Mollicone, M. Rezende, D. Routh, C.M. Zohner and T. Crowther, Science, *365*(6448), p. 77.

The findings of studies by Bond et al. (2019), Brockerhoff et al. (2008) & Hajdu et al. (2016) demonstrate that there is a variety of risks to the upscaling of tree planting initiatives. This is particularly relevant when they are implemented on unsuitable land, or on land falsely classified as degraded and in need of restoration (Bond et al., 2019; Brockerhoff et al., 2008; Hajdu et al., 2016). They criticize the assumptions that were made by Bastin et al. (2019), such as using forest cover as a measure to state a biome or ecosystem as degraded, which assumes that land with low forest cover is deforested (Bond et al., 2019; Brockerhoff et al., 2008; Hajdu et al., 2016). As a consequence, grass-dominated ecosystems such as grasslands and savannas have mistakenly been included under the bracket of degraded land in need of restoration by tree planting programs. An example is the case of the initiative AFR100 contributing towards the Bonn Challenge, which has targeted the conversion of 100 million hectares of African continental land consisting mainly of grasslands (Bond et al., 2019). Classifying grasslands and savannas as degraded lands requiring forest restoration poses challenges. This includes the disregard for the carbon stored in grasslands belowground, which may lead to a potential net warming effect if converted as forestry would absorb more incoming radiation than grasslands (Bond et al., 2019). Depending on a number of factors of the site e.g. previous land cover and the planted trees' composition, this may also have significant temporal repercussions on the existing biodiversity of specialist and generalist forest species' population numbers (Brockerhoff et al., 2008).

Tree planting has increasingly been seen as a viable solution to help address the environmental pressure of deforestation, particularly occurring in tropical forests which are under threat of conversion for other land uses e.g. pasture lands, arable farming – for the production for human consumption and animal feed. Deforestation peaked during the 1980s and 1990s and as a result, half of the tropical forest that was present at the start of the 20th century has been lost (Morris, 2010). Deforestation has also been one of the major drivers (along with habitat fragmentation, degradation, overexploitation, climate change and invasive species) behind the decline of forest vertebrate populations, which have halved between 1970 and 2014 on average (WWF, 2019a). As a result the implementation of reforestation projects (as forest restoration) has been used widely as a policy instrument to help reverse the consequences that deforestation and climate change have on the environment and for society (Hua et al., 2016).

The study by Brockerhoff et al. (2008) found that on appropriate land the implementation of plantation forests can contribute to biodiversity conservation of remaining native forests, through habitat supplementation of forest species. This can enable the "connectivity between indigenous forest remnants" and can be used as a buffering effect for surrounding native forest areas (Brockerhoff et al., 2008, p. 932). However, there is debate to what extent a secondary forest can compensate and/or restore the species richness and biodiversity that was lost from the deforestation.

Forest animals also contribute essential services for the management and maintenance of healthy forests that subsequently benefit society (WWF, 2019a). They provide crucial roles in processes affecting carbon storage and natural regeneration such as herbivory, seed dispersal and pollination (WWF, 2019a). Furthermore, the biodiversity of both flora and fauna also correspond with the production of a number of other ecosystem services including pest control, mitigating the spread of disease and soil erosion (Thompson et al., 2011). Consequently, tree planting of forests can help support biodiverse fauna through connectivity to different forest fragments. Although, despite the well-known links between ecosystem services (e.g. water and air purification), functional traits and biodiversity, there is still a knowledge gap on how ecosystem services recover from different restoration efforts (Chazdon, 2008).

Tree planting projects may also be implemented and governed for economic and commercial purposes, for example to produce and harvest timber and non-timber products, pulp and fuelwood, to generate carbon credits and for agroforestry. For instance, the global consumption of wood products has steadily increased, where paper and solid wood products have increased by 4.0% per annum from 1980 to 2007 (Ajani, 2011).

Additionally, around the period of the 2000s the Ecosystem Marketplace estimated that carbon credits were worth US$92 million for the purchase of more than 880,000 hectares of agricultural land and forest land used for carbon sequestration (Jindal et al., 2008). In addition, the Clean Development Mechanism developed by the Kyoto Protocol has provided valuable financial inflows for industrializing countries to execute carbon sequestration projects, which has helped to lift small land owners out of poverty (Jindal et al., 2008).

In certain cases the misjudgements of prioritising specific objectives for tree planting can also have a substantial impact. For example, Fischer et al. (2019) found that the establishment of the Kachung plantation as a climate forest (in Uganda) caused the loss of tree diversity and hindered local women's access to useful trees and farmland. This resulted in them experiencing a heavier work burden and increased livelihood struggles. However, societal impacts like these, have led to a more participatory process for affected stakeholders and communities to have a say in tree planting and forestry projects. The introduction and implementation of Forest Landscape Restoration (FLR) initiatives by WWF over the last 20 years have included this as a focus point to improve human wellbeing in deforested and degraded forest areas alongside the restoration of ecological functionality in the landscape (WWF, 2019b). This approach enables the creation of a mosaic landscape of different land uses to address different objectives, e.g. a designated forest area for production and harvest and a designated area for natural forest conservation (WWF, 2019b). Using this heterogeneous landscape approach, certain trade-offs can then be more effectively managed to ensure project site priorities are met (WWF, 2019b; Chazdon, 2008).

Depending on the objective of a tree planting project, it can fall under different classifications/categories such as afforestation or reforestation projects, consisting of either monocultures (typically for production purposes) or mixed-species cultures (usually for forest restoration purposes). These can be comprised of native or exotic species, or as a mix (Schroeder, 1992; Liu, Kuchma & Krutovsky, 2018). Additionally, factors such as the historical natural state/previous land cover of the chosen site may impact the effectiveness of carbon sequestration and storage (Schroeder, 1992), the conservation of biodiversity and/or the local hydrology of the site.

There is a knowledge gap in academia for meta-analyses of characteristics of current tree planting project sites located around the world. This is particularly the case when looking into the different measures these programs apply to their projects and the attributes of project sites. An example of this would be which type of tree species were planted for different project sites, as well as which have implemented measures for biodiversity conservation or for the local water management of their project sites. For current and future tree planting sites to improve in ecological functionality, key variables must be identified and understood. Additionally, assessing consequences and drawbacks of different practices (variations within key variables), can contribute to an improved understanding of more ecological sustainable practices. Furthermore, discovering the extent to which measures are applied to monitor or enhance biodiversity of project sites may highlight the urgency that issues such as biodiversity loss have, and so these must be addressed. Therefore, based on this and the literature findings the following research aim was created for this thesis project.

Research Aim, Research Questions and Hypotheses

The research aim is to develop an inventory of tree planting program sites and identify key ecological variables that may influence carbon sequestration, biodiversity conservation and water management of a project site. For each site, data will be collected on the physical attributes of the site; i.e. country of project site, continental region of the project site, previous land-use, terrestrial ecosystem, the planted tree species, the primary project site objective. Additionally, the prevalence of measures or monitoring for biodiversity conservation and local water management will be explored. This research was conducted with an extensive literature review, expert interviews and with quantitative methods.

Therefore, this research aims to identify the differences in both measures and key ecological variables between current tree planting project sites to provide an open discussion in approaches and decision-making for the tree planting project design and the ecological appropriability of a site. This research could provide an opportunity to reflect on critique or to discuss actions for key areas for improvement of current tree planting projects. This could prompt the collaboration and sharing of local and specialized knowledge of methods and practices to apply to tree planting sites.

Addressing the aim of this research study also contributes towards the Sustainable Development Goal 15, Life on Land, through exploring and drawing conclusions based on the extent measures are taken by tree planting programs for biodiversity conservation efforts or sustainable forestry management of project sites. Based on the research aim, the following research questions and their respective sub-questions were composed combined with the stated hypotheses.

Research Question 1: What are the key ecological variables for best practices of tree planting program sites?

Hypothesis: The key ecological variables (Table 2) are expected to be identified in literature as influential factors to carbon sequestration, biodiversity conservation and local water management. It is expected that the literature review and expert interviews will show that reforestation (not afforestation) projects using mixed-native tree species, will be recommended to be more ecologically sustainable. It is expected that literature will indicate that planting a mix of native species may enhance the resilience and survival of the forest as the native trees will be already acclimatized to the local climate.

Research Question 2: How are tree planting initiatives distributed across the globe?

Hypothesis: There is an expectation that tree planting sites will be found in terrestrial ecosystems of the tropics region where there is faster biomass productivity rates e.g. tropical and subtropical moist broadleaf forests and tropical and subtropical grasslands, savannas & shrublands. It is expected that tropical type terrestrial ecosystems will feature significantly more for tree planting sites than other ecosystems, due to their faster biomass productivity rates, whereas it is anticipated that boreal type ecosystems will feature significantly less for tree planting sites. This will most likely be due to the comparatively slow biomass productivity rates of more northern latitudes of boreal ecosystems, despite native boreal tree species having a greater carbon sequestration potential. Additionally, it is hypothesized that a majority of tree planting projects, especially reforestation projects (and not afforestation projects) will be located in countries with higher deforestation rates and a low forest cover area, due to global political pressures for forest restoration in these areas. Moreover, it is expected that there will be a significantly larger proportion of afforestation project sites in the tropical grassland terrestrial ecosystem (than any other terrestrial ecosystem type), due to the biomass productivity rates as well as the likelihood of grasslands being mistaken as ‘degraded land’.

Research Sub-question 2.1: How do tree planting project sites differ in types of previous land cover used for the project sites?

Hypothesis: It is forecasted that of the afforestation tree planting sites there will be significantly more project sites with grasslands as the previous land cover. In the cooler temperate or boreal type terrestrial ecosystems, land cover such as peatlands are hypothesized to be the previous land cover of afforestation sites.

Research Question 3: How do tree planting program sites differ in terms of primary or secondary objectives (e.g. carbon sequestration) and their key ecological factors?

Hypothesis: It is predicted that tree planting sites will feature heterogeneity with their ecological factors particularly between different terrestrial ecosystems. However, it is expected that a significantly greater proportion of tree planting sites will be for the primary purpose of commercial & production activities rather than for forest restoration purposes. For the secondary objective it is anticipated that a greater proportion of project sites will be for carbon sequestration purposes.

Research Sub-question 3.1: How do tree planting sites differ in key ecological factors such as the composition and type of tree species planted?

Hypothesis: It is envisaged that a significant proportion of the tree planting sites will be monocultures, as they may be more economically affordable to plant than mixtures of tree species and easier to clear cut for commercial services. It is presumed also that the use of solely exotic species will be significantly greater for afforestation projects rather than the use of native species. However, native species are assumed to be planted significantly more at sites for reforestation projects.

Research Sub-question 3.2: How do tree planting program sites differ in the implementation of measures taken and in the monitoring of biodiversity conservation of their respective sites?

Hypothesis: There is a likelihood that biodiversity conservation measures have been implemented significantly more for project sites that have a secondary objective of improving the biodiversity of the project site and surrounding forest areas. It is also expected that these same project sites will also have biodiversity monitoring implemented as part of the project plan.

Research Sub-question 3.3: How do tree planting program sites differ in the implementation of measures taken and in the monitoring of local water management of their respective sites?

Hypothesis: There is a presumption that in terrestrial ecosystems of a drier climate there will be a significantly greater proportion of tree planting sites with implemented measures or monitoring for water management, to reduce moisture deficit for the local landscape. Whereas, in wetter types of terrestrial ecosystems it is expected that significantly less tree planting sites have implemented local water management measures and monitoring, likely due to a moisture surplus.

Summary of Research Questions and Hypotheses

The first research question identifies and develops a deepened understanding of key ecological variables (see Table 2). These chosen variables were further investigated for the inventory (research question 2 & 3). They were chosen as they were identified to potentially have an influence on a tree planting site with regards to carbon sequestration, biodiversity conservation and/or local water management practices. The second research question (and sub-questions) explores the climate and geography of the chosen tree planting sites. This question aims to investigate which terrestrial ecosystems are the most targeted for tree planting and aims to determine whether there is an association between the different types of tree planting (e.g. reforestation or afforestation projects). The third research question has a closer focus to understanding the different project purposes in comparison to a few different ecological variables (e.g. type of tree planting) between different tree planting project sites. Additionally, the third research question also investigated which tree planting program sites have implemented measures or monitoring for biodiversity conservation and local water management.

Theory

As forest restoration and regeneration has become more at the forefront of the global political agenda, many countries are assessing what contributions they can make to reach global goals e.g. the Bonn Challenge. However, some geographical areas and types of terrestrial ecosystems may be more focused on tree planting project opportunities than others. There may be several reasons for this, for example, the biomass productivity rate and time frame for financial return may make tree planting projects more attractive in some types of ecosystems than others. Also the availability of economic opportunities for tree planting, as well as the organization and capacity of the country/geographical region may draw attention to tree planting sites of a specific geographical area or biome than others.

Based on current statistics, plantations represent 4% of global forest area, whilst there is a growth rate of planting trees and forests at 2.8 million hectares per year for production, restoration and conservation purposes (Chazdon, 2008). The majority of global forest area is found in the tropical climate domain (45%) followed by the boreal climate domain (27%) (Figure 2a). Additionally, of the total global forest area the Russian

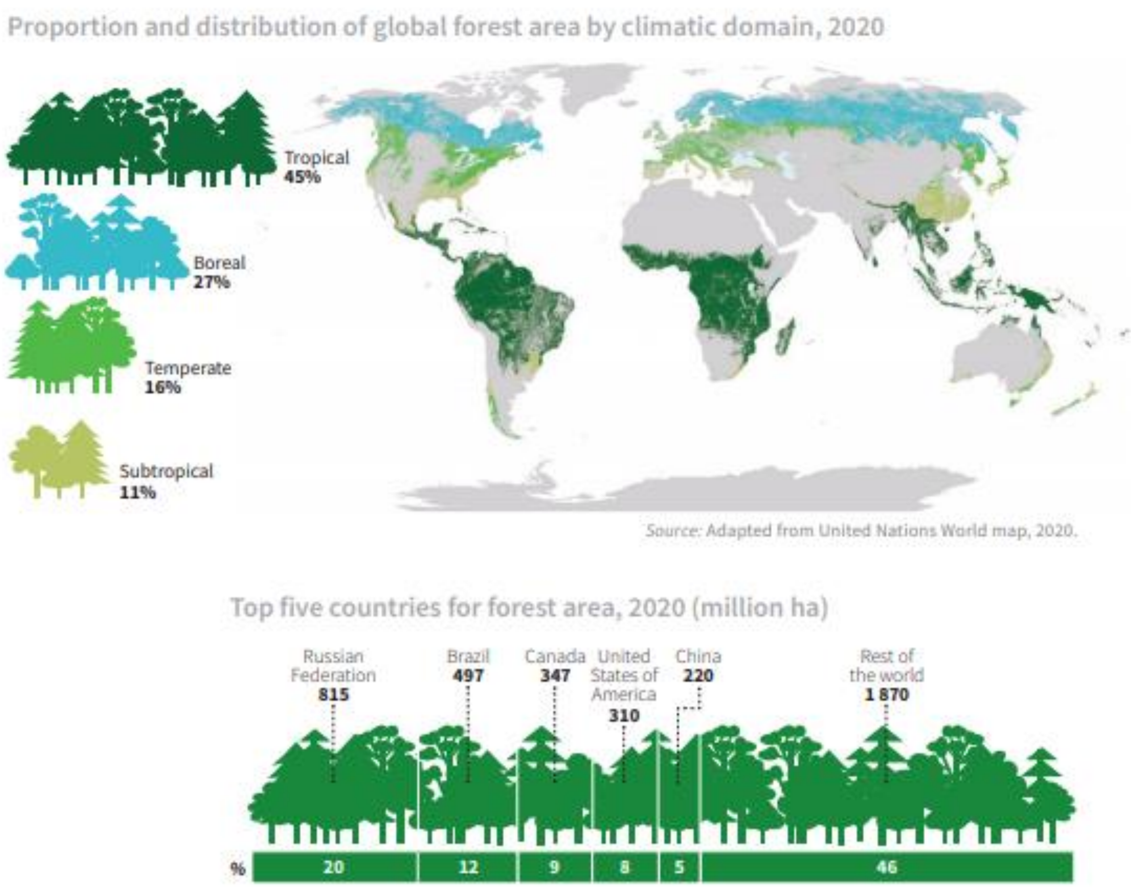

Figure 2a & 2b. 'The proportion and distribution of global forest area by climatic domain in 2020 and the top five countries for forest area in 2020' (measured in million hectares) (FAO, 2020, p. 1). Reprinted from 'Global Forest Resources Assessment 2020 - Key findings' by Food and Agriculture Organization (FAO) of the United Nations, 2020, Rome. Retrieved from: http://doi.org/10.4060/ca8753en, p. 1.

Federation, Brazil, Canada, the United States of America and China host the most forest area per country (Figure 2b). Therefore, a key ecological factor that may influence the particular distribution or motivation of setting up a tree planting project site is location – e.g. continental region or the specific type of terrestrial ecosystem of a site.

However, to establish an understanding of the different key ecological factors and measures that may or may not influence carbon sequestration, biodiversity conservation and local water management of a chosen tree planting site, it is important to define key concepts/terms of the topic. Definitions are necessary to communicate and clarify the understanding of concepts. For example definitions enable ecologists and policymakers to share a common ground of understanding a particular ecological mechanism, process or variable, where scientific knowledge is applied in governance as policy directives and regulations or laws (for local governance to international governance). Therefore, definitions have a great significance in how they are used to convey, highlight and direct discussions in scientific research, policy and governance and in the private sector.

Definitions of concepts that shape current policies and research could originate from outdated knowledge and findings. Looking at specifically tree planting, it is important to acknowledge that 'forest definitions provide the conceptual, institutional, legal, and operational basis for the policies and monitoring systems that drive or enable deforestation, forest degradation, reforestation, and forest restoration' (Chazdon et al., 2016, p. 538). Also one concept/term can vary greatly in definition between stakeholders, due to their different respective goals and objectives (Chazdon et al., 2016). For example "forest" has several definitions which have emerged in order to facilitate & achieve objectives of its use and management by the different stakeholders (Chazdon et al., 2016) (see Table 1). Reasons for the planting or managing of forests include examples such as; (a) to generate profits for the timber industry, e.g. the definition by FAO (refer to Table 1) (b) for the conservation of biological diversity in efforts of tackling deforestation, e.g. the definition by CBD (c) climate change mitigation, e.g. the definition by UNFCCC and (d) for Earth stewardship of using the ecosystem services of forests for sustainable development and poverty alleviation, e.g. the definition by Chapin et al. (2011), (Chazdon et al., 2016). Moreover, tree plantations fall under the definitions of "forest" by FAO (2000) and UNESCO (see Table 1), which may further blur the lines of what is distinguished as natural and a man-made forest (Romijn et al., 2013). Although, these discrepancies between different definitions may appear minute, they can cause cascading effects for the decision-making surrounding the topic and concept definitions in question. There is historical evidence of 'oversights in the communication of ecological knowledge that translated into long-lasting policy prescriptions with negative environmental and social consequences' (Veldman et al., 2017, p. 650). Therefore, it is considerably alarming to see how certain components/concepts are neglected or may be misrepresented in the defining of terms such as "forest".

Furthermore, it is essential to recognize where there may be bias or misrepresentation in defining concepts. As more tree planting programs are created under the narrative to 'restore forests globally on degraded land', some research studies have drawn focus to the chosen definition for 'land degradation'. These studies have further investigated how the choice of definition has over time impacted the decision-making to plan, accelerate and scale-up more tree planting programs as strategies to meet international objectives e.g. the Bonn Challenge. Veldman et al. (2017) discusses further on the consequences of misrepresenting what is meant by degraded land, where some tree planting sites have been mistakenly implemented in grass-dominated ecosystems (e.g. savannas). Grass-dominated ecosystems and other low tree cover ecosystems have been referred to as “barren lands” or “dysfunctional”, falsely labelled as deforested land (Veldman et al., 2017). In the study by Bastin et al. (2019), the land proposed to have global tree restoration potential has mistakenly defined degraded land as land dominated by ‘sparse vegetation, grasslands, and degraded bare soils’ (Bastin et al., 2019, p. 77). The chosen definition of degraded land by Bastin et al. (2019) and other studies has significant problematic consequences to the global scale of land conversion of valuable ecosystems (such as grasslands) as they are continually targeted and threaten the conservation efforts of their state stability as an ecosystem (Murphy et al., 2016). As a result ‘misperceptions about the world’s grass-dominated ecosystems are contributing to their alarming rates of loss due to conversion for agriculture and tree plantations, as well as to forest encroachment’ (Veldman et al., 2015). Therefore, the definitions of ecological terms/concepts can have significant repercussions on decision-making, thus, it is important to be critical for bias and misrepresentation.

Term/Concept	Definition	Reference
Afforestation	'planting forests where they did not historically occur'	(Veldman et al., 2015, p. 1011)
	'planting trees on a site that has not been in forest for 50 years or more, if ever'	(Schroeder, 1992, p. 32)
Biological Diversity	'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'	(CBD, 2007, p. 5)
Ecological Restoration	'assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed'	(SER, 2002) Cited from Holl et al. (2003)
Ecosystem	'A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.'	(CBD, 2007, p. 5)
Forest	Land spanning more than 0.5 ha with more than 10% tree canopy cover and trees higher than 5 m (or having the potential to reach a height of 5 m).	FAO, 2000
	0.5–1.0 ha forest land, 10–30% tree canopy cover and 2–5 m of tree height.	UNFCCC Cited from Romijn et al. (2013)
	Vegetation cover dominated by intertwined tree crowns with canopy cover of more than 60%	UNESCO Cited from Romijn et al. (2013)
	A dynamic complex of plant, animal and micro-organism communities and their abiotic environment interacting as a functional unit, where trees are a key component of the system.	CBD Cited from Chazdon et al. (2016)
	A complex system composed of heterogeneous assemblages of individual agents (e.g. trees, animals, humans), closely interacting through flows involving markets, goods and various other ecosystem services.	Chapin et al., 2011 Cited from Chazdon et al. (2016)
Generalist species	'Live in forests but also occupy one or more other habitats.'	(WWF, 2019a, p. 15)
Habitat	'The place or type of site where an organism or population naturally occurs.'	(CBD, 2007, p. 5)
In-situ conservation	'Conditions where genetic resources exist within ecosystems and natural habitats, and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties.'	(CBD, 2007, p. 6)
Land degradation	'A long-term loss of ecosystem function and services, caused by disturbances from which the system cannot recover unaided.'	(UNEP, 2007, p. 92)
	The decline of natural land resources, commonly caused by improper use of the land	(Bergsma et al. 1996) Cited from Wiegmann et al. (2008)
	'A loss of forest structure, productivity, and native species' Diversity. A degraded site may still contain trees or forest but it will have lost its former ecological integrity. Degradation is a process of loss of forest quality that is in practice often part of the chain of events that eventually leads to deforestation.'	(WWF, 2019b, p. 23)

Landscape Patterns	the spatial relationships of ecosystem types	(Forman & Godron, 1986) Cited from Holl et al. (2003)
Plantation Forestry	'Cultivated forest ecosystems established through planting or seeding of native or introduced species under the process of afforestation or reforestation'.	(Liu et al., 2018, p. 3)
Protected area	'A geographically defined area which is designated or regulated and managed to achieve specific conservation objectives.'	(CBD, 2007, p. 6)
Reforestation	'planting trees on deforested land' 'planting trees on a site that was recently in forest'	(Veldman et al., 2015, p. 1011) (Schroeder, 1992, p. 32)
Specialist species	'comprise species which live only in forest habitat'	(WWF, 2019a, p. 15)
Sustainable use	'The use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations.'	(CBD, 2007, p. 6)

Table 1. Key definitions of terms and concepts that will be explored for the purposes of this research project.

Although, typical biomes that feature forest ecosystems include temperate, tropical, boreal and Mediterranean (WWF, 2019a), it is important that the previous land cover and terrestrial ecosystem was identified prior to planning a site for tree planting. Also as land and vegetation are not homogeneous throughout a biome, previous land cover must be considered, along with the terrestrial ecosystem type, as an ecological factor, influencing the environmental suitability of a site. Furthermore, a species of native flora or fauna found in a particular area can be defined as a 'species that has been observed in the form of a naturally occurring and self-sustaining population in historical times' (Smith et al., 2018). Another factor is whether the tree plantation is executed as an afforestation or a reforestation project. Tree plantations established through afforestation where natural ecosystems (such as natural and semi-natural grasslands) are converted, may negatively impact fauna e.g. grassland specialist native species, which can have cascading effects, altering the area's grazing regimes and local drainage, as trees increase the water uptake from the land (Bremer & Farley, 2010). Afforestation in this case can also cause a loss in native plant diversity (Bremer & Farley, 2010). Shade intolerant native species will no longer be able to compete for sunlight due to the tree plantation canopy cover, and the litter from the planted trees can create a physical barrier (particularly pine litter) on the forest floor disrupting germination of native plant species (Bremer & Farley, 2010). Contrastingly, afforestation on previous agricultural land has been found in some studies to be assisting biodiversity conservation efforts for forest species, by providing complementary forest habitat (Brockerhoff et al., 2008). Moreover, whether the tree species planted is native or exotic may also play as a significant ecological factor for biodiversity conservation. For example, the study by Zurita et al. (2006) found that in the Atlantic forest, threatened bird species were found only in plantations of native tree species, and not in those of exotic trees. However, in this study, natural native forests were also found to have a 50% higher bird species richness when compared to both native and exotic tree plantations (Zurita et al., 2006). Currently today it was found that plantations in North & Central America as well as Asia have a larger proportion of native tree species compared to exotic tree species for plantations based on the findings of the FAO (2020) global report (Figure 3). Whereas, Africa, Europe, Oceania and especially South America have been found to have a much greater proportion of exotic tree species for plantations (Figure 3; FAO, 2020).

The composition of the trees planted either as a monoculture or as mixed species of trees, as another ecological factor, may also influence variables such as local biodiversity conservation. Several studies have discovered that by increasing the diversity of tree species planted can increase the number of different types of habitats for native species and increase the resilience and resistance of the planted forest to human and natural disturbances (Brockerhoff et al., 2008). Furthermore, the extent to which biodiversity measures are implemented, and depending on which measures they are, they may also have a significant role for the biodiversity conservation of a chosen tree planting site. For example, implementing silvicultural measures, i.e. improving forest belts around stands and designating areas within the plantation for the protection of forest remnants can contribute to conserving bird species communities (Zurita et al., 2006).

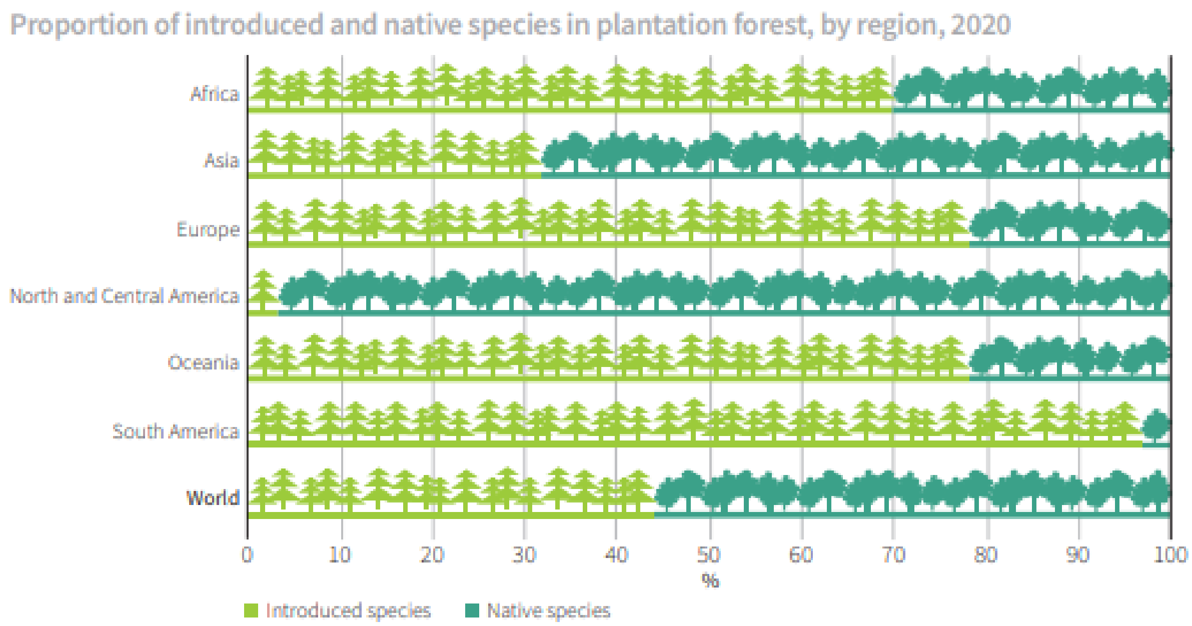

Figure 3. 'The proportion of introduced and native species in plantation forest, by region, 2020' (FAO, 2020, p. 6). Reprinted from 'Global Forest Resources Assessment 2020 - Key findings' by Food and Agriculture Organization (FAO) of the United Nations, 2020, Rome. Retrieved from: http://doi.org/10.4060/ca8753en, p. 6.

Many ecosystem functions and some original biodiversity can be restored with forest restoration projects (Chazdon, 2008). However, it is also important to take into account that approaches to restore functionality (of biodiversity and ecosystem services) are very dependent on financial constraints, the time frame and the state of degradation of the site in question and the desired outcome (Chazdon, 2008) (Figure 4).

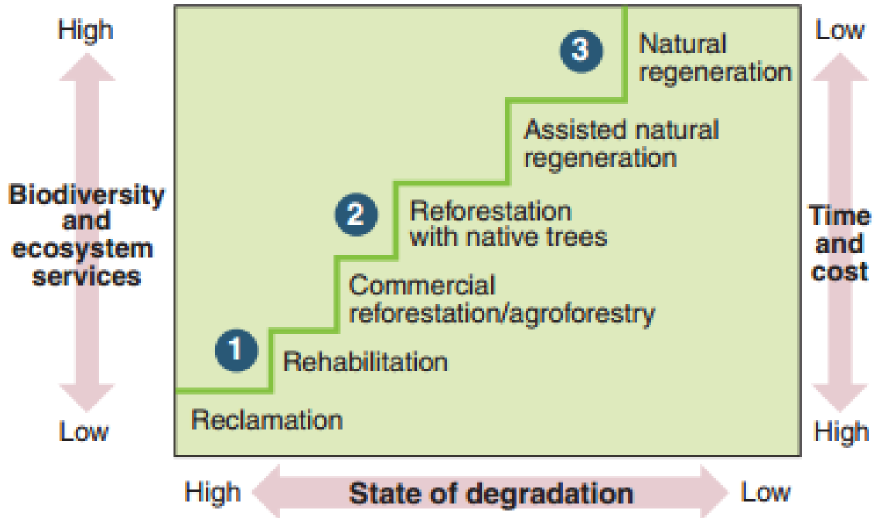

Figure 4. The restoration staircase. 'Depending on the state of degradation of an initially forested ecosystem, a range of management approaches can at least partially restore levels of biodiversity and ecosystem services given adequate time (years) and financial investment (capital, infrastructure, and labour). 'Outcomes of particular restoration approaches are (1) restoration of soil fertility for agricultural or forestry use; (2) production of timber and nontimber forest products; or (3) recovery of biodiversity and ecosystem services' (Chazdon, 2008 p. 1459). Reprinted from 'Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands,' by R.L. Chazdon, 2008, *science*, 320(5882), p. 1459.

Forest landscape restoration projects, to halt deforestation and degradation and enhance natural regeneration can consist of a variety of interventions, but may not always include tree planting, for example, implementing measures to restrict industrial activities in biodiversity areas. However, 'there's a lot of potential to work with reforestation as a strategy of forest landscape restoration' (T. Walter, personal communication, March 20, 2020). The design, planning and execution of forest landscape restoration requires an involvement of a variety of stakeholders, and a specific consideration to planting appropriate species for the place, the people, the ecosystem and the outcomes desired looking at the landscape scale (T. Walter, personal communication, March 20, 2020). Facilitating engagement with the private sector can also help the scaling up of work in the landscape but ensures that existing system degradation is corrected as an outcome (T. Walter, personal communication, March 20, 2020). Another component of the work is ensuring when a stakeholder such as WWF (in role of consultation and guidance) withdraws from a reforestation project, it is ideally expected that restoration work is continuously followed up by the companies and stakeholders involved, as well as monitored and reported on in an annual audit for instance, to maintain a project site's Forest Stewardship Council (FSC) certification which WWF works with (T. Walter, personal communication, March 20, 2020).

Methodology

The following research framework was created to demonstrate the different stages of research undertaken for this master thesis project. This framework addresses the different steps needed to answer the research questions provided earlier and the methodology used for these steps (Figure 5). A mixture of qualitative and quantitative methods was applied for the data collection of this study.

Research Framework

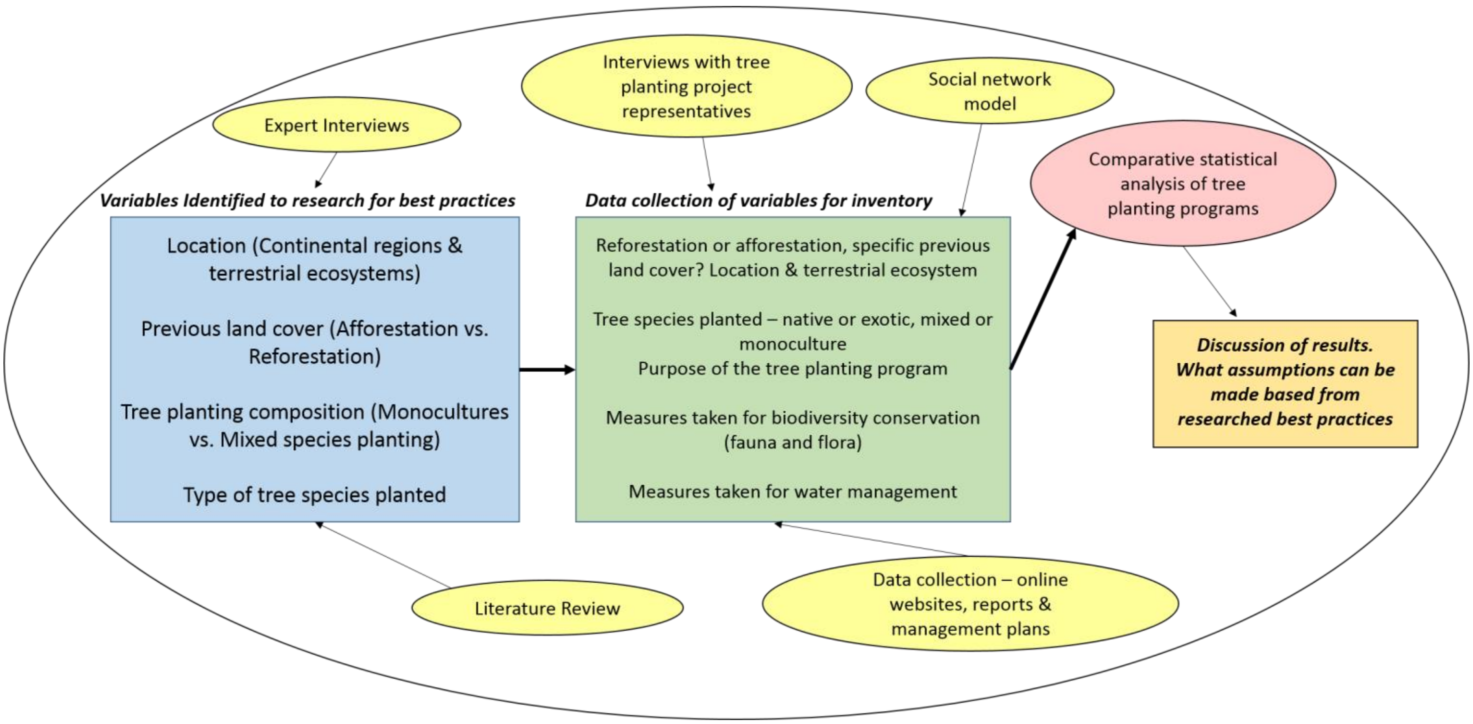

Figure 5. The research framework of the Master thesis project. The blue and green blocks represent the two different stages of research, exploring the variables in literature for best practices and which variables will be subject for data collection of tree planting program sites. The yellow ovals represent the methodology used for each stage (block) of the research. A comparative statistical analysis of tree planting sites was conducted in succession of the stage of data collection on the chosen variables, as shown by the red oval. The orange block represents the discussion component of the research, to draw conclusions and assumptions when combining the two stages of research together (how the characteristics of the tree planting program sites match or comply against the researched best practices and the theory).

Qualitative data collection

For the first research question a literature review was conducted to identify and explore the key ecological variables for criteria of recommended best practices (see Table 2). The literature review has contributed to understanding how these identified key ecological variables may influence carbon sequestration, biodiversity conservation and local water management. Therefore, the literature review supports why the chosen ecological factors are important or relevant to investigate between different tree planting sites for this research project. Moreover, nine semi-structured interviews with experts from the field of landscape restoration forest management and nature based solutions were conducted to support or challenge the literature findings (with their informed consent). This was done by contacting and requesting interviews with a number of experts via email or LinkedIn. The literature for review was retrieved from searching key concept terms such as "natural based solutions", "CC mitigation" or "biodiversity measures" (and similar concepts as explained further in Table 2) in Google scholar to source academic journal articles and books. Further recommended reading materials were collected from interviewed experts and the supervisors of this project. On the basis of these methods a document highlighting the recommended criteria of the identified key ecological variables for best practices was created. This was one of the end products of the internship for WWF to use for their own critical reflection/improvement of their forestry projects.

Theme	Key ecological variables
Location	Continental/geographical region Terrestrial Ecosystem type
Previous land cover	Afforestation Reforestation
Tree planting site composition	Monocultures Mixed-species cultures
Type of tree species	Native Exotic
Measures for biodiversity	e.g. ensuring connectivity
Measures for local water management	e.g. planting native species in the riparian zone

Table 2. Examples of the key ecological variables (and their respective theme) for best practices criteria that will be identified and explored to answer the first research question.

Quantitative data collection

To find tree planting programs to survey (to answer the second and third research questions), websites of multinational corporations e.g. Shell, were searched for tree planting programs or initiatives that they may support or partner with. For each tree planting program that was further explored online, there may be one to a dozen different project location sites, where one site represents 1 data point. When new connections were identified (Figure 6) of new found tree planting programs they were next targeted for data collection (surveying from online websites or reports). In the end, 113 data points were collected of different project location sites from 20 different leading tree planting programs/project partners. Of the 20 tree planting programs it was found that the majority of their headquarters are located in Europe and only some in North & Latin America as well as Asia & Oceania (Figure 7). However, it was unexpected to find that none of the headquarters of the programs are located in Africa despite nearly a quarter of tree planting project sites being located in Africa. The number of international project sites and size of the different tree planting programs sampled is further demonstrated in Table 4, Appendix A.

The main data collection method was online data collection from websites and reports of tree planting programs and their respective project webpages. This data was used to create and develop an inventory of tree planting sites on the variables tested for research question 2 & 3 (Appendix A; Figure 26a & 26b). A further six semi-structured interviews (using interview guides; for example see Appendix B) were also conducted with only significant tree planting program representatives to gain further insights and information on project sites where data was less accessible to retrieve online.

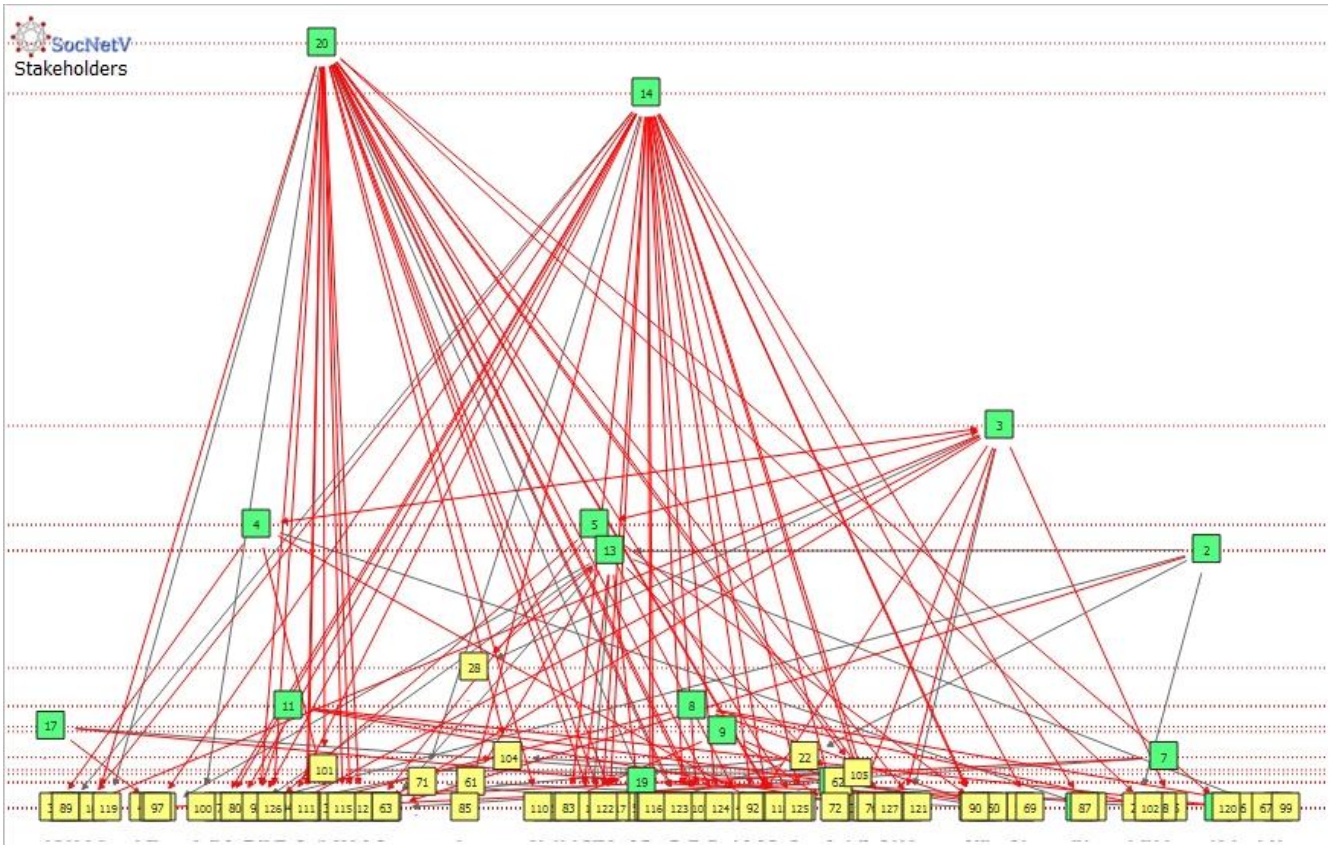

Figure 6. A visualized social network analysis model of the leading partners of tree planting programs (the green squares) and the stakeholders involved a tree planting program/the leading partner (the light yellow squares), *N* = 127. This figure displays the interconnectedness between different stakeholders for different tree planting programs. This model presents the two different type of stakeholders involved (nodes) showing the closeness centrality of the network, where nodes are positioned based on their closeness to one another (looking at the shortest paths) and shows more clarity on which stakeholders are most likely to impact the rest of the network. In this case leading tree planting program partner 14 and 20 (at the top level) hold the highest influence in this particular model.

The data collected was retrieved from websites and from interviews with tree planting program representatives and filled into an inventory on Microsoft Excel. The inventory included the data of the different key ecological variables for each data point/tree planting site (Appendix A; Figure 26a & 26b). However, the methods for quantitative data collection differed between each different key ecological variable. Firstly, the data for the Human Development Index of a country and the HDI ranking of 2018 were sourced from a report of the United Nations Development Programme (2019). The terrestrial ecosystems of project sites were classified accurately by matching the location described on the tree planting project website to an online global map using the database of World Wildlife Foundation of their defined "terrestrial ecoregions" of the world (O'Neill, 2020).

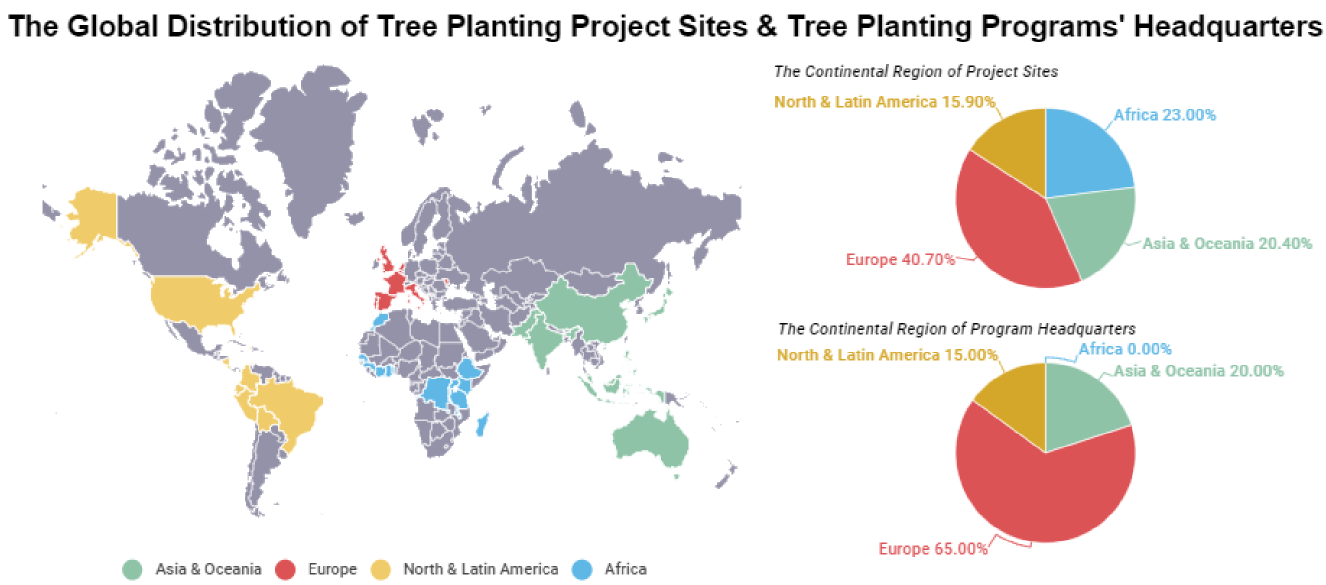

Figure 7. A map of the countries and continental regions where the tree planting project sites that were analysed are located, (*N* = 113) and the continental regions where the tree planting program headquarters are located (*N* = 20).

Moreover, the certification and standard used for a project site was either found on the program website or from accessible project documents. For the variable forest cover percentage of the country in 2015 (%), data was collected from a website by Roser (2013) that was summarized from the UN Food and Agriculture Organization's data. Whereas, the data for the forest area annual net change rate between 2010 – 2015 (%) of a country was sourced from a website by the United Nations (2020). Additionally, the type of tree planting of a project site was determined depending on how a project was labelled on the project site's webpage by the tree planting program. Therefore, this variable was determined by the program's interpretation of whether the project was a reforestation, afforestation or mix of both types of tree planting. Variables such as the previous land cover, previous land use, the primary objective and secondary objective of project sites were categorized after collection based on reoccurring themes. The composition of tree planting and the type of tree species planted was dependent on the information provided on the project/program website, as well as accessible project documents. If the information provided described that more than one species had been planted then the project would be described as mixed species planting, but this was in the event that there were no maps which demonstrated that the project site was spilt into areas of monocultures and mixed species planting. This was also the case when data was collected for the type of trees species planted, if the project's website informed that there was planting of both exotic and native tree species (regardless of the proportion between them), then the project site would be classified to have mixed tree species planting in the inventory.

The methodology proposed aimed to be as objective as possible for the sampling of the data. However, in reality it was much more difficult to keep the sampling consistently objective searching for large multi-corporations and their participation or partnership with specific tree planting programs. This was due to the lack of information and accessible data of the tree planting program(s) they were involved in. Another reason for this inconsistency during data collection was due to the connections and networks available with the pressure of time constraints. This meant that it was easier to acquire an interview with a tree planting program representative through my own independent connections as well as through the WWF network, in comparison to contacting numerous individuals of multinational corporations and their partnered tree planting program(s). Therefore, based on the connections and the time constraints, a number of smaller scale tree planting programs were also included within this study. It is important to note that this may had led to some biases within the distribution and results of this research study.

Data Analysis

For the data analysis of the quantitative data collected the program SPSS was used to perform statistical analyses. The chi-square test for independence as well as the test for the Cramér's V coefficient (ϕc) was conducted to test the relationship between nominal variables. The Cramér's V (ϕc) test was used in order to determine the strength of the intercorrelation between two variables which outputted a value varying from zero (indicating there is zero association) to one (indicating that there is a perfect association). These tests were used to test for significant associations (between the response and predictor variables respectively) to answer the second research question between i) the type of tree planting labelled for a project site versus the terrestrial ecosystem of a project site (N = 53) and ii) the type of tree planting labelled versus the continental region of a site (N = 86). For the third research question the following associations were also statistically tested, iii) the primary objective of a project site versus the continental region of a site (N = 107), iv) the primary objective of a project versus the terrestrial ecosystem of a project site (N = 62), v) the secondary objective of a project versus the continental region of a site and vi) the primary objective of a project versus the Human Development Index (HDI) ranking of a project site's country. Additionally, a linear regression analysis was performed to test the relationship between the forest area annual net change rate between 2010 – 2015 (%) of a project site's country against the country's forest cover (%) in 2015. These statistical tests have helped to determine the significance of results, as well as the strength of an association (depending on the data that was available and accessible). However, despite the total sample size of 113 project sites it was found that depending on the association investigated between two variables, missing data was present which influenced the sample sizes and the possibility of conducting some statistical tests.

Results

Research Question 1: What are the key ecological variables for best practices of tree planting program sites?

The following section analyses four main identified factors: location, previous land cover, tree planting site composition and type of tree species; and how they influence the carbon sequestration, biodiversity conservation and local water management of a tree planting project site. Wherefore, a detailed analysis of each factor is presented based on the findings of an extensive literature review, as well as a summary of significant challenges based on expert interviews. These factors were then investigated for current tree planting project sites, addressing research question 2 & 3.

Location

It is suggested that by 2050 due to current climate trends, there could be a shrinkage of 223 million hectares in the global potential canopy cover of trees, with the tropics being affected most (Bastin, 2019). In the study by WWF (2019a) it was found that tropical forests are also the most biodiverse forests in the world. However, the tropics is the only region to demonstrate a trend of forest loss of 2101 square kilometres per year between the years 2000 till 2012 (Hansen et al., 2013). However, due to the climatic conditions within the tropics forest biome, tropical tree species have rapid growth and short cycles, which has become a great economic opportunity for appreciable gains (Namkoong et al., 1980). These gains could be for the productive use of the forest through harvest and/or for carbon sequestration purposes where 10 years cycles of tropical tree plantations can range in estimates from 1 to 3.4 Mg C ha^{-1} y^{-1} in mean carbon sequestered (Bond et al., 2019). The short cycles mean that a plantation of Eucalyptus in Southern Brazil or South Africa could be grown within 7 years and between 12 to 15 years for timber (L. Neves Silva, personal communication, March 18, 2020).

Fast species growth and shorter cycles experienced in the tropics can not only be beneficial economically but can also be advantageous for the rapid succession of a secondary natural forest planted. This happens through different stages where the pioneer species of vegetation replace shade intolerant species, until eventually a mature community of specialist species is formed (a climax forest) (Hansen et al., 1991; Christensen & Peet, 1984). For the process of succession, species can fall under three different categories, ‘pioneer species’ which provide soil cover, ‘intermediate species’ which grow due to neighbouring species and ‘climax species’ that grow during the final stages of forest succession, despite the conditions of shade (Ball et al., 1995).

The high biomass productivity of tree species in the tropics has made it an attractive geographical area to implement tree planting projects for conservation or commercial purposes. As a result, the approach of implementing ecological corridors of natural forest for Forest Landscape Restoration (FLR) is particularly adopted in the tropics (L. Neves Silva, personal communication, March 18, 2020). This is because applying this same mosaic approach in other geographical areas becomes complicated where the tree cycles are slower, as is the case for boreal type forest ecosystems where cycles can be more than 100 years (L. Neves Silva, personal communication, March 18, 2020).

Moreover, historically there has been motivation to implement tree planting for the most degraded geographical areas globally. Reforestation has historically been present over the continent of Africa and South America over the last 10 years, particularly towards achieving targets for the Bonn Challenge and to meet government pledges (D. Valluari, personal communication, April 27, 2020). In some areas such as the Atlantic Forest of Brazil, it has been highly degraded and deforested which has meant that reforestation and restoration efforts have been ongoing for the last 20 years (D. Valluari, personal communication, April 27, 2020). On the other hand, countries in Asia host large areas of degraded land and Indonesia and Malaysia in Asia are among the highest for experiencing an increase in forest loss between 2000 and 2012 (Hansen et al., 2013; D. Valluari, personal communication, April 27, 2020). There has also been an increase in political pressure for forest restoration efforts to be applied elsewhere globally, where the European Commission have released "The European Green Deal" with a Biodiversity strategy including a target to plant at least 3 billion trees by 2030 as a part of the EU's COVID-19 recovery plan (European Commission, 2020).

The decision of the location of a tree planting project should also account for the forest type planted, whilst evaluating the effect of long term risks of future climate changes on the project. It is expected that 'all forest types will undergo some change' over the next 50-100 years from the effects of widespread climatic change (Thompson et al., 2009, p. 43). Boreal forests are well adapted for current conditions and can recover from regular disturbances, but due to their latitude they are expected to 'undergo the greatest increase in temperature from climate change scenarios' (Thompson et al., 2009, p. 31). However, it is predicted that most boreal forests (consisting of few tree species but of which many are dominant) and some temperate forests will have ecological resilience against the climatic trends (Thompson et al., 2009). It is expected that many rainforests may become dry tropical forests, also resulting in a reduction of carbon storage capacity (Thompson et al., 2009). Moreover, even if there is severe disturbance it is expected that tropical forests may persist due to their high biodiversity, although the effectiveness of the tropical forests' ecosystem functions may be diminished (Thompson et al., 2009).

Consequently, the recommendations for best practices of tree planting can vary greatly depending on a location's latitude, biome and terrestrial ecosystem, i.e. an FLR approach is most suitable in the tropics. However, an opportunity has been presented to restore previously forested and degraded land (that has been correctly verified) domestically in Europe and Asia, to reach national and international commitments e.g. SDGs, rather than focusing all restoration efforts in the tropics. Moreover, tree planting in the tropics may contribute to generating fast appreciable economic gains (from plantations), but it is also likely to have the greatest impact to stabilizing ecosystems with most biodiverse forest species populations through natural forest regeneration. Still, it is crucial that tree planting projects must account for the risks and environmental pressures that climate trends may have for the long term viability (the overall tree survival) of a project. From the literature it is claimed that boreal and temperate forests are likely to be the most ecologically resilient to climate change (Thompson et al., 2009). However, these findings may be subjected to future developments once more certainty is known of climatic trends and scenarios.

Type of previous land cover

In the cases where tree planting programs target grass-dominated ecosystems for forest restoration (afforestation), a number of environmental costs may arise. The grass-dominated ecosystems under conversion will be incompatible with the settlement of newly dense forest, causing light-dependent herbaceous plants to die-off. This would likely reduce the carbon stored belowground and may further threaten the loss of the herbivorous mammals, who maintain the grassland landscape through their feeding and burrowing activities (Veldman et al., 2015; Bond et al., 2019; Davidson et al., 2012). Moreover, the converting of grasslands for tree planting can greatly affect nutrient cycles and the hydrology of an area, since trees demand more soil nutrients and water in comparison to forbs and grasses (Veldman et al., 2015). Subsequently, afforestation projects in grasslands can also cause a decrease in the stream flow and the groundwater recharge, causing land drainage (Veldman et al., 2015; Bremer & Farley, 2010). Consequently, forest restoration projects should be cautious when using indicators for potential forest regeneration based on the spatial distribution, abundance and the quality of the remaining vegetation (Chazdon, 2008).

Organizations such as WWF and the Nature Conservancy, as examples, do not advocate the conversion of natural ecosystems (e.g. grasslands, wetlands etc.) for tree planting projects and programs (L. Neves Silva, personal communication, March 18, 2020; S. Cook-Patton, personal communication, March 23, 2020). 'WWF is opposed to the indiscriminate conversion of natural ecosystems that have high conservation values and/or critical carbon storage functions to plantations, croplands, pastures, urban settlements and other land-uses' (WWF, 2008, p. 1). The Nature Conservancy also excludes tree planting activities on very high value land types such as 'productive cropland, urban areas' as well as places where it's not feasible to plant additional trees (S. Cook-Patton, personal communication, March 23, 2020). However, finding a biophysically appropriate site can be a challenge. Where sites are found to be barren or land that no longer supports a productive ecosystem, it is important that the land is carefully monitored or measured for degradation prior to planning tree planting activities for the site. Although, measured variables such as deforestation and forest connectivity are easy to analyse, degradation is a difficult variable to measure (D. Valluari, personal communication, April 27, 2020). Where degradation is defined as the loss of ecosystem function or natural capital of land (Table 1) there are a number of methods to measure it. One example is the use of satellite imagery of the Normalized Difference Vegetation Index (NDVI), which is already used as a yardstick of global land degradation (Bai et al., 2013). Another example is the Land Degradation Neutrality (LDN) framework 'to maintain or enhance land-based natural capital and its associated ecosystem services' (Cowie et al., 2018, p. 25). This particular framework developed by the United Nations Convention to Combat Desertification (UNCCD), uses land productivity (net primary productivity), soil organic carbon stocks (SOC) of above and below ground and physical land cover (to indicate land use) as key indicators and metrics to analyse for degradation (Cowie et al., 2018).

While there are a variety of different methods to measure degradation there are also numerous restoration options depending on the site and location. These can vary from restoration projects on marginal crop and pasture lands, to the restoration of protected areas of forests experiencing the threats of environmental disturbances to sites, which can provide a stacking of co-benefits from a tree planting restoration project (S. Cook-Patton, personal communication, March 23, 2020).

Tree planting projects (both afforestation and reforestation) are sometimes implemented to address a prioritized co-benefit/objective of the local landscape or to achieve a multiple stack of co-benefits/objectives to increase the value in a project. These co-benefits can range from high ecosystem service benefits/payments (from carbon accumulation and biodiversity conservation) and other environmental co-benefits (e.g. water quality and quantity, erosion control, soil conservation) (Brown et al., 2008; Bryan et al., 2016; Trotter et al., 2005). There also can be a variety of social co-benefits, such as poverty alleviation, human right protections and the strengthening of forest governance (Brown et al., 2008; Bryan et al., 2016; Trotter et al., 2005). These co-benefits may hold more value than others, depending on the country's political priorities and what pressures they face (from local to national scale). However, to choose an appropriate restoration approach, it is important to consider the environmental conditions of the site and local landscape to increase the persistence of a project for the long term (S. Cook-Patton, personal communication, March 23, 2020). For example, in the case of designing a forest carbon sequestration project several issues may arise that may jeopardize the success of a project (*Box 1*).

Challenges of designing forest carbon sequestration projects

For the design of forest carbon sequestration projects a number of challenges can arise: heterogeneity, uncertainty, additionality and permanence (Gren & Aklilu, 2016).

The issue of heterogeneity regards the differences of geo-hydrological and climatic conditions between different regions which can vary the carbon sequestrated per unit of land depending on the project's location (Gren & Aklilu, 2016). Another issue is uncertainty, this can be present as errors in measuring and monitoring carbon sequestration (Gren & Aklilu, 2016). There also may be issues of uncertainty due to the variation of weather conditions and other unforeseen environmental disturbances that may impact biomass productivity and growth of the trees planted (Gren & Aklilu, 2016). Additionality refers to whether a tree planting forest project for the purpose of carbon sequestration is implemented 'without a compensation payment for carbon sequestration' (Gren & Aklilu, 2016, p. 129). Similarly to uncertainty the permanence of carbon sequestered may be hindered by weather conditions (changes in precipitation and temperature) and natural disturbances (e.g. wildfires) (Gren & Aklilu, 2016). Permanence may also be affected if there is a breach of project rules such as harvesting prematurely to the project's end date (Gren & Aklilu, 2016). Permanence of carbon sequestered is also affected by the chosen use of the wood products, for instance wood products harvested to be used as housing building materials can sustain the carbon sequestered for a longer time than wood products that are used as bioenergy for heating (Gren & Aklilu, 2016).

Another obstacle to the implementation of forest carbon sequestration projects is the transaction costs of 'search, negotiation, monitoring and enforcement of projects' (Cacho et al., 2013, p. 242). However solutions such as peer-monitoring schemes of smallholders measuring and monitoring their own plots of trees can help lower the costs of transaction (Cacho et al., 2013).

Box 1: Factors which present challenges to the design of carbon sequestration based forest projects.

A number of tree planting programs for carbon sequestration purposes have complied with certification schemes to validate the measurements of carbon sequestrated at their respective sites, e.g. to enter the carbon credit market. Examples of such carbon forestry management certification schemes include, Climate, Community and Biodiversity (CCB) Standards, Gold Standard for Global Goals, the Verified Carbon Standard (VCS) and Forest Stewardship Council (FSC). However, certifications issued by an independent third party can be considered as an economic barrier for some programs, as it can be an expensive process (S. Cook-Patton, personal communication, March 23, 2020).

Land use and land cover change (LULCC) also has a substantial impact on the global carbon cycle, either resulting in the emission of CO_2 into the atmosphere, or the sequestration of carbon dioxide (Almulqu & Boonyanuphap, 2017). The study of Tagesson et al. (2020), has also estimated that between the years 1992 and 2015, the process of LULCC has led to an 'increase and decrease of the contributions of boreal and tropical forests, respectively' towards the global terrestrial carbon sink (Tagesson et al., 2020, p. 202). This trend was also estimated based on the net effect of several drivers, including LULCC along with meteorological forcing, CO_2 fertilization and nitrogen deposition (Tagesson et al., 2020). Therefore, depending on the nature of the previous land cover of the project site, the conversion of the land for afforestation may contribute to LULCC, and thus indirectly influence carbon dioxide emissions. This section has shown the importance of recognizing the state of degradation and identifying whether there is a functioning ecosystem of the land prior to the planning of a tree planting project. However, it also has summarized the challenges, consequences and risks surrounding tree planting that may occur as a direct or indirect result of implementing a project on ecologically inappropriate land.

Type of tree species planted

Forest plantations for the timber, pulp & paper industry have been planted across the globe (Wingfield et al., 2001). Plantations of the Northern Hemisphere typically consist of native species, where seedlings are grown in nurseries (Wingfield et al., 2001). Contrastingly, in the tropics and Southern Hemisphere there has been a vast expansion of exotic plantations, where breeding programs have enabled the selection of species with the most desirable genotypes to propagate (Wingfield et al., 2001). In this region the most common plantation tree species are '*Pinus Linnaeus'*, '*Eucalyptus L'Heritier'*, and *'Acacia Miller*' (Wingfield et al., 2001). Additionally, currently in 2020, the continents of South America, Oceania, Europe and Africa have been found to have a higher percentage of exotic species (also known as introduced species) than native species (FAO, 2020). Meanwhile, Asia and particularly North and Central America have a greater focus on using native tree species for plantations according to current statistics (FAO, 2020).

However, the establishment of exotic plantations has had some negative localized environmental consequences, with the introduction of new pests and pathogens and in some cases exotic species have become invasive (Wingfield et al., 2001). An example is the *Morus papyrifera* tree (also known as paper mulberry), which was introduced and has invaded several countries over the last few decades (Micheal et al., 2013). As an invasive tree species, it has had significant impact in Pakistan, where the pollen of paper mulberry is 'a major cause of respiratory allergy' (Micheal et al., 2013, p. 169). Exotic trees for plantations can feature a number of 'traits that are characteristic of invasive species: easy establishment, fast growth, high propagule pressure, and low or intermediate shade tolerance' (Dodet & Collet, 2012, p. 1765). Moreover, the risks of invasivity are particularly present in areas of high soil fertility, high biodiversity hotspots and areas with high herbaceous foliar cover (Stohlgren et al., 1999). Thus, mitigating and managing the risk of invasivity of planted exotic tree species is a challenge (Stohlgren et al., 1999). However, several management strategies have been implemented at different stages to slow down and control the process of invasion, such measures are especially important for controlling the populations of *Pinus* and *Acacia* type trees (Dodet & Collet, 2012).

Another issue with exotic tree species is that they are commonly fast growers, which usually use more water than species with slower growth (Carnus et al., 2006). Thus, as part of forest management, exotic trees must be planted a certain distance from rivers, streams and other water bodies (L. Neves Silva, personal communication, March 18, 2020). Native trees and vegetation are planted around water purses and bodies to act as buffer areas, to protect riparian zones as one of the requirements of Forest Stewardship Council (FSC) certification (T. Walter, personal communication, March 20, 2020). Tree planting is also advantageous for local water management where it reduces the 'nutrient run-off from adjacent lands' into local waterways, but can also be used as a flood management strategy (S. Cook-Patton, personal communication, March 23, 2020). However, the establishment of exotic tree plantations can also have other negative environmental impacts such as negatively altering the chemical, physical and biological conditions of a site's soil, and can potentially displace native flora and fauna elsewhere (Feyera et al., 2002).

Despite the negative risks and challenges that can arise with exotic plantations, their high levels of productivity (from fast growth and easy establishment) means that they can 'have strong direct positive economic impacts on the local and national economies of many countries' and can help generate profits for small landowners (Dodet & Collet, 2012, p. 1765). Furthermore, tree plantations are increasingly using exotic tree species due to two key reasons; (1) there is 'readily available information on propagation techniques, silvicultural behaviour and management practices' and (2) their initial 'fast growth rates, and production of wood that can be used for various purposes in a relatively short period of time' (Feyera et al., 2002, p. 246). Furthermore, particularly in the tropics little knowledge is known about propagating and collecting the seeds of native species so it can take a longer time to start up projects involving native tree species (D. Valluari, personal communication, April 27, 2020).

From a conservation perspective, the goal from forest restoration is to increase the cover of native tree species (T. Walter, personal communication, March 20, 2020). However, how beneficial is planting native tree species over the planting of exotic tree species, and do the benefits of planting one type outweigh the other?

Firstly, for a forest to gain ecological integrity as a key component of FLR, the forest needs to be in 'a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change, and supporting processes' (WWF, 2019b, p. 18). Thus, this is only achieved if there is a great range of native species. Furthermore, ecosystem function (its productivity) and parts of the ecosystem's structure (such as the canopy) can be restored from planting a 'diverse range of native species assemblages' in terrestrial ecosystems (Wright et al., 2009, p. 170).

Secondly, when planning and designing a tree planting project the species chosen to be planted ideally should be chosen bearing in mind the future changing climate and how tolerant or adapted it may be to such changes (D. Valluari, personal communication, April 27, 2020). It is also important to be aware there may be a possibility that future climate scenarios may cause the physical forest system to collapse if it is unable to adapt and survive, which will release a lot of carbon (D. Valluari, personal communication, April 27, 2020). This may be very problematic, if the trees planted were planted solely for the purpose of carbon sequestration and did not hold any other purposes or co-benefits to validate and justify the planting of them. Thus, when choosing an appropriate species to plant it may be beneficial to search for species that may be tolerant to future climate conditions, and if that species is found over a wide geographical range it may be an effective approach to choose Southern genotypes and move them towards a northern end of the range (S. Cook-Patton, personal communication, March 23, 2020). Tree migration is a slow process, thus this approach may help the species keep up with the migrating climate (S. Cook-Patton, personal communication, March 23, 2020).

Type of tree planting composition

'There is very much the debate of single species versus multiple species, native species versus exotic species' (Neves Silva, personal communication, March 18, 2020). The composition of a forest or the trees planted can have a significant role in enhancing or conserving biodiversity and forest succession, depending on what the purpose and overall objective is of the trees planted. For instance, in silviculture it is essential to understand the mechanisms or measures needed, to ensure the successful growth of trees planted so an overall good quality and healthy plantation is achieved.

Whereas, if tree planting is executed on degraded pastures or deforested land for restoration purposes, it is important that pioneer species of trees become established (in some cases they will be previously grown into saplings in a nursery). This is because these species will grow fast and will outcompete the remaining exotic species vegetation for resources, thus, eliminate them (D. Venturi, personal communication, April 22, 2020). In the Atlantic Forest Restoration Pact, as an example, it is recommended that pioneer species and a diverse set of species are planted together, two by two or two by three (D. Venturi, personal communication, April 22, 2020). This enables the process of succession from pioneer to mature forest. From this approach it is important that the newly planted forest is evaluated for at least two years, but ideally into the long term, to check for the ecological condition and growth of the forest (D. Venturi, personal communication, April 22, 2020).

There is evidence that using this approach of forest succession from tree planting can remove the ecological barriers to succession that 'might otherwise preclude re-establishment of native species' providing that there is 'a local source of propagules, dispersal agents, and a favorable climate' (Brockerhoff et al., 2008, p. 930). As mentioned previously, the early stages of succession are the result of trees' planted influence on the vegetation structure, accumulation of humus and litter layers and on the microclimate conditions of the understory (Brockerhoff et al., 2008). As shade intolerant species e.g. species of grass (that would typically stunt tree seed germination or the growth of seedlings) become suppressed from competition, the microclimate conditions (moisture, temperature and light) improve for the growth of the pioneer trees planted (Brockerhoff et al., 2008). Moreover, the growth of the forest may attract seed dispersing fauna bringing neighbouring native tree seeds into the local forest system (Brockerhoff et al., 2008). This could potentially bring more flora diversity to the forest of the tree planting site, if the regeneration of woody story is permitted in managing the forest (Brockerhoff et al., 2008). It is also important that there is a balance between not planting the trees too densely, so that no understory plant species can grow, but at the same time enough so that the exotic shade intolerant species is eliminated in the early stages of succession (WWF, 2019b). The outcome of forest succession can therefore feature a diversity of flora from neighbouring forests, as well as a greater number of both late and early successional tree species (Brockerhoff et al., 2008). The study of Brockerhoff et al. (2008) found that the process of succession has been present in both the tropics and subtropics, and also in plantations of both exotic and native tree species. The study also found that a variety of native species' populations are able to survive the successive rotations of a plantation (Brockerhoff et al., 2008). Thus, from a biodiversity conservation perspective, mixed species planting is more likely to increase the forest's species biodiversity particularly for flora species when compared against a monoculture with intensive silviculture management of removing understory vegetation.

Furthermore, mixed species planting can also be found to be more ecologically advantageous than planting monocultures. A mixed species plantation is not only a more suitable habitat for native species, but can also improve nutrient cycling and has greater resilience and resistance to environmental or human disturbances (Ball et al., 1995; Brockerhoff et al., 2008). Resistance can be better understood as 'the ability of the system to resist external stress' and resilience can be defined as 'the ability of a system to return to its former dynamic state after being influenced by a perturbation, whether natural or anthropogenic' (Ball et al., 1995, p. 302). Mixed species plantations are more resilient against environmental and human disturbances like climate change and pathogens or pests, and can more easily sustain the fertility of the tree planted site regardless of the threat (Ball et al., 1995). Also physically mixed species plantations are less susceptible to buffering effects such as wind blow (Ball et al., 1995). Therefore, biodiversity can be used as a measure for resilience, where 'the resilience of a forest ecosystem to changing environmental conditions is determined by its biological and ecological resources' (J. Woning, personal communication, March 16, 2020; Thompson et al., 2009). This includes the 'diversity of species, including microorganisms', the 'genetic variability within a species' as well as 'the regional pool of species and ecosystems' (Thompson et al., 2009, p. 7). Forests stands are also more resilient if they are heterogeneous in age. To have sustainable tree stands (with tree planting for non-harvesting purposes) it is therefore also important that the planted trees are from different cohorts of age to avert a die out of all the planted trees at the same time (Anonymous expert, personal communication, April 7, 2020).

From the perspective of local water management the factor of tree composition in terms of using a singular species of trees versus a mixed-species composition can pose little significance. Studies have shown that there appears to be little variation between monocultures or mixed-species sites with regards to water quality or to yields of water from catchment (Carnus et al., 2006).

Main challenges of tree planting projects

Currently, there still remains to be a number of challenges involved in the design, planning and implementation of a tree planting project, from an ecological perspective and a societal/political perspective. Significant challenges surrounding these themes are discussed based from the expert interviews conducted.

Firstly, for the objectives of current international/national commitments and pledges (e.g. Bonn Challenge) to be met, efforts such as forest landscape restoration require scaling up from all parties involved (A. Diederichsen, personal communication, March 12, 2020; T. Walter, personal communication, March 20, 2020). To overcome the barriers to scaling up forest restoration efforts, stronger governance is needed to increase the perceived value of implementing efforts (A. Diederichsen, personal communication, March 12, 2020). There also needs to be improved communication in demonstrating how forest restoration efforts can reap benefits, not only environmentally but also economically and socially (A. Diederichsen, personal communication, March 12, 2020; T. Walter, personal communication, March 20, 2020). For the potential and the desired scale and goals of restoration to be met, more funding needs to be found (T. Walter, personal communication, March 20, 2020). Therefore, finding funding to pay off restoration projects can be a large barrier, for the costs of opportunity, implementation and for monitoring (D. Venturi, personal communication, April 22, 2020). However, legal compliance to ensure that landowners from the forestry industry designate an area/percentage of their property of land for native restoration (depending on the country and their respective laws on forestry e.g. Forest code of Brazil), can alleviate this financial barrier to a certain extent but it is an all-encompassing solution (D.Venturi, personal communication, April 22, 2020). This is particularly the case for longer term projects which may have greater uncertainty as legislation may be subjected to change (D. Venturi, personal communication, April 22, 2020).

Consequently, another challenge is engaging with the public and convincing communities as well as private landowners to be interested in and connected to the restoration projects. In addition, there must be enough funding to ensure that established projects then have continuous work or are monitored by the different stakeholders involved in the short, medium and long term future, for the survival of the planted forests (T. Walter, personal communication, March 20, 2020).

However, scaling up efforts for forest restoration are not just limited financially to reach capacity, but also may be limited due to the availability and supply of seeds (D. Venturi, personal communication, April 22, 2020). Moreover, there may not be the capacity to produce 'plants that are genetically diverse with precedents from the area that is chosen as the tree planting site' (T. Walter, personal communication, March 20, 2020). Where it is possible to plant a variety of diverse native species' seedlings, invasive species can hinder the growth of the native seedlings. The success of tree planting projects is additionally dependent on the site itself, as it can be difficult to find appropriate sites where planted trees may last for the sustainable long term future (S. Cook-Patton, personal communication, March 23, 2020).

To resolve these issues (using the appropriate land and species planted) for appropriate tree planting for restoration purposes to occur at a greater scale, engagement with the private sector, landowners and local communities must be strengthened (D. Venturi, personal communication, April 22, 2020). If tree planting projects are also demonstrated to provide multiple economic elements / ecological co-benefits (e.g. flood management, agroforestry), it may prove to be easier to incentivize as a funding opportunity, validating 'the ecosystem as a valuable part of us in our society and our economic system' (J. Woning, personal communication, March 16, 2020). Providing 'an altruistic approach to ecosystem restoration with an activity that is economically interesting to individuals, groups, companies or governments' may support the case for long term allocation of resources to tree planting projects (T. Walter, personal communication, March 20, 2020).

Research Question 2: How are tree planting initiatives distributed across the globe?

To investigate this research question on the global distribution of tree planting projects, a relationship between the types of terrestrial ecosystem project sites locations was tested against the type of tree planting project described (Figure 8).

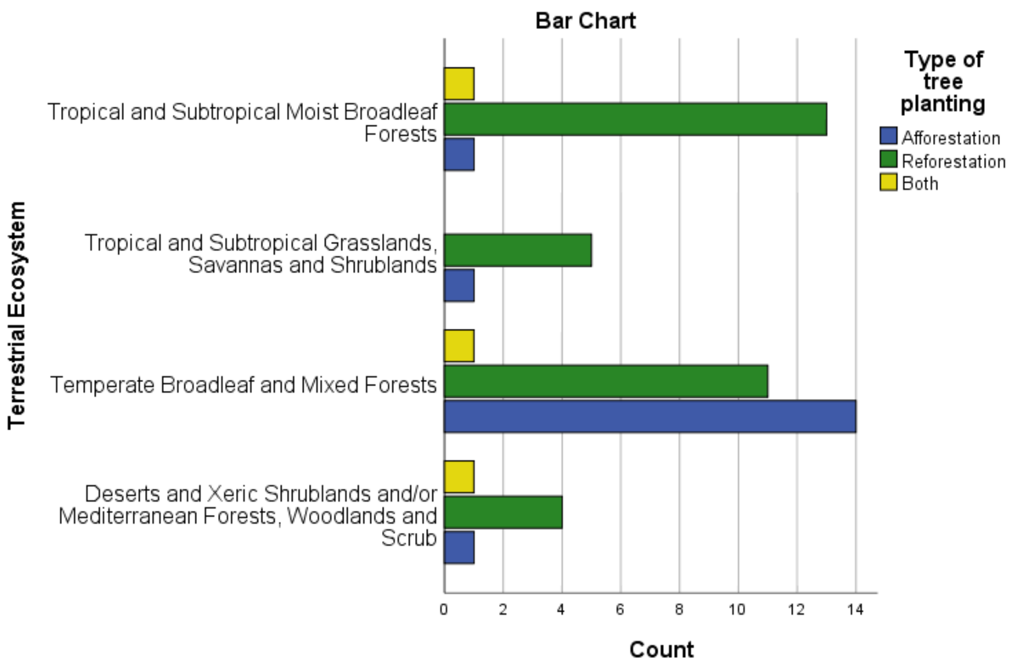

Figure 8. A bar chart of the number of locations of different types of terrestrial ecosystem tree planting project sites depending on the terms ("Reforestation", "Afforestation", or "Both"), as described on the tree planting program website ($N = 53$). Some terrestrial ecosystem categories were excluded from this analysis e.g. "Tropical and Subtropical Dry Broadleaf Forests" due to their small count size (see Table 5, Appendix A). The terrestrial ecosystems were accurately defined using WWF data from O'Neill (2020). A chi-square test of independence was conducted ($p < 0.05$).

A significant association between the terrestrial ecosystem of a tree planting project site and the type of tree planting term used was observed, χ^2 (6) = 13.095, $p = 0.042$. It was found that the strength of the association is only moderate between these two variables using the Cramér's V test $\phi c = 0.351$, $p = 0.042$. Consequently, the type of tree planting is likely to be dependent on the terrestrial ecosystem of the project site. Projects labelled as afforestation have a much greater frequency in the temperate broadleaf and mixed forests type of terrestrial ecosystem than any other type. Conversely, the projects labelled as reforestation are most common in tropical and subtropical moist broadleaf forests ecosystem type as well as the temperate broadleaf and mixed forests ecosystem type. There are less differences found between terrestrial ecosystems for projects labelled with a mixture of afforestation and reforestation.

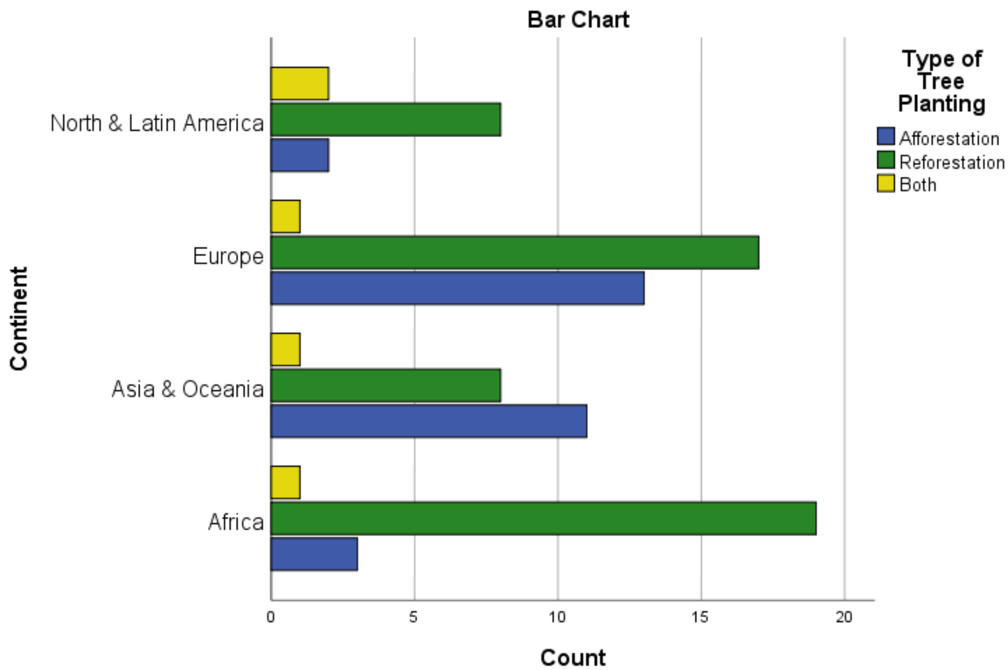

Figure 9. A bar chart of the tree planting project sites distribution over the continental regions compared with the type of tree planting term that was provided on the tree planting program website "Reforestation", "Afforestation" or a mix of both terms (N = 86). A chi-square test of independence was conducted ($p < 0.05$).

A significant association between the continental region of a tree planting project site and the type of tree planting term used was observed, χ^2 (6) = 13.642, p = 0.034. There was also found to be a significant but weak association between these two variables ϕc = 0.282, p = 0.034. In accordance to Figure 9, it is found that projects labelled as reforestation were mainly found in Africa followed by Europe. Projects that were labelled as afforestation have been planted mainly in Europe followed by Asia & Oceania.

Research Question 2.1: How do tree planting sites differ in types of previous land cover used for tree planting sites?

The largest proportion of project sites from the data collection are located in Europe and the smallest proportion are located in the continental region of North & Latin America. As shown in Figure 10, all the continental regions except Asia & Oceania (including half of project sites with the degraded land as the previous landcover) have a greater proportion of reforestation tree planting projects than afforestation or a mix of the two types.

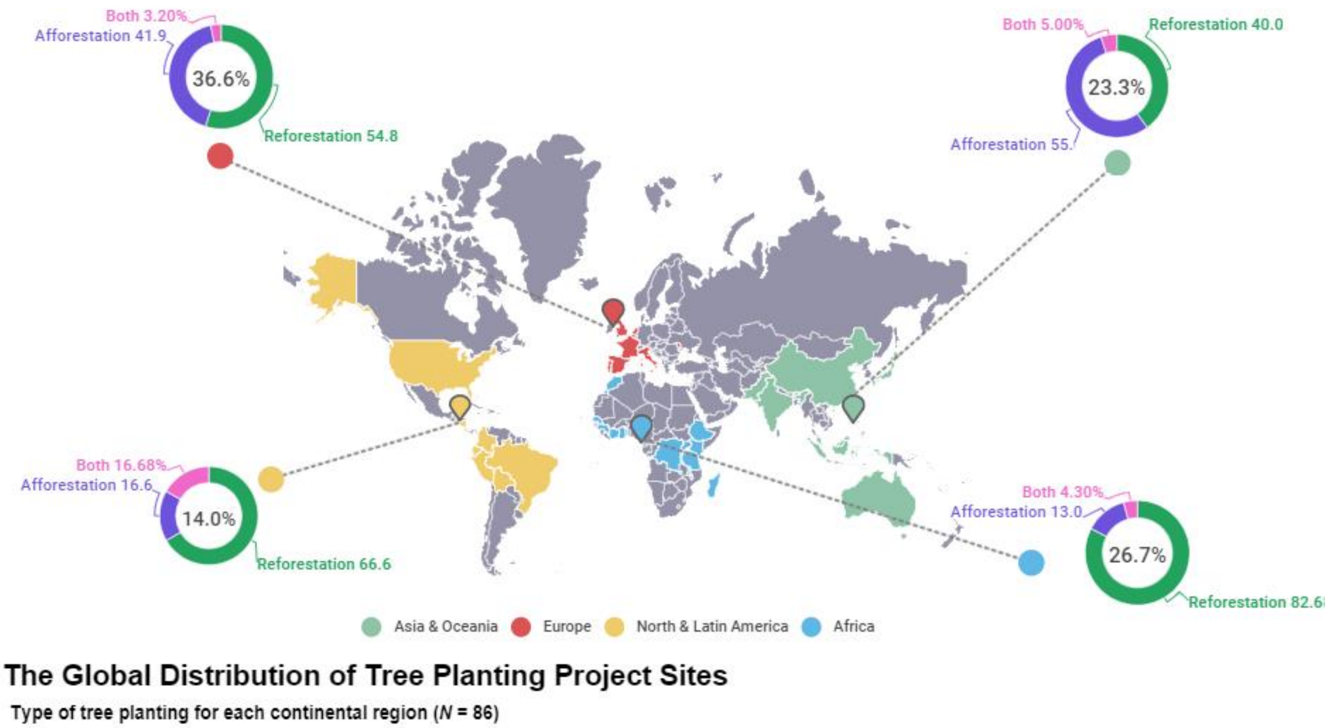

Figure 10. An infographic showing the distribution of the tree planting project sites and the type of tree planting that is labelled for each site (e.g. "Reforestation", "Afforestation" or both) is investigated for each continental region. Percentages around the circles represent the proportion of the type of tree planting in the continental region, whereas the percentage in the centre of the circles represent the percentage per continental region of the total sample size.

Degraded land is the most common previous land cover of tree planting project sites in Asia & Oceania and Africa. Contrastingly, the project sites of Europe show that degraded forest is the most common type of previous land cover (Figure 11). Despite the large majority of projects labelled as reforestation in Africa, degraded forest as a previous land cover features substantially less than degraded land (Figure 10 & Figure 11).

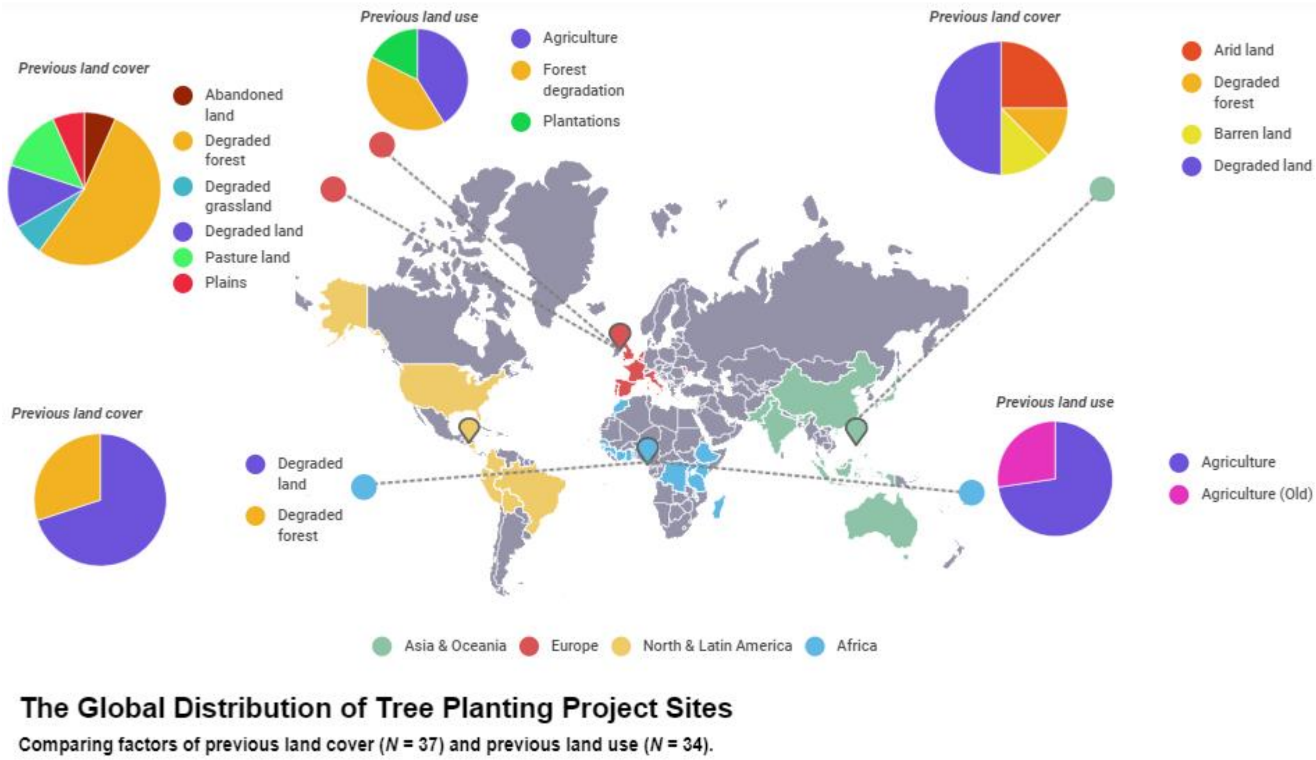

Figure 11. An infographic that shows the distribution of tree planting project sites alongside the type of previous land cover and land use found between the different continental regions. This includes subsets (previous land cover & land use) based on the data that was available. Due to the low availability of data for previous land use of Asia & Oceania as well as the previous land cover and previous land use of North & Latin America, pie charts were excluded for these continental regions. The previous land use and cover was categorized based on reoccurring themes within the data e.g. old agricultural land.

To understand further the motivations of tree planting and the resulting global distribution of the data collected, the project sites of the 38 countries included in the sample were compared for their forest cover (%) in 2015, alongside their rates of forest regeneration or deforestation within the years 2010 to 2015. With a linear regression analysis a very low or no correlation was found between these two variables. The $R^2 = 0.001$ indicates that the forest cover (%) of a project site's country in 2015 accounts for some 0.1% of the variance in the forest area annual net change rate between 2010 – 2015 (%) of that country. The distribution of data points for the type of tree planting are too widely spread to indicate that there is any association between the type of tree planting labelled compared with the forest cover (%) of a project site's country in 2015 and the country's forest area annual net change rate between 2010 – 2015 (%).

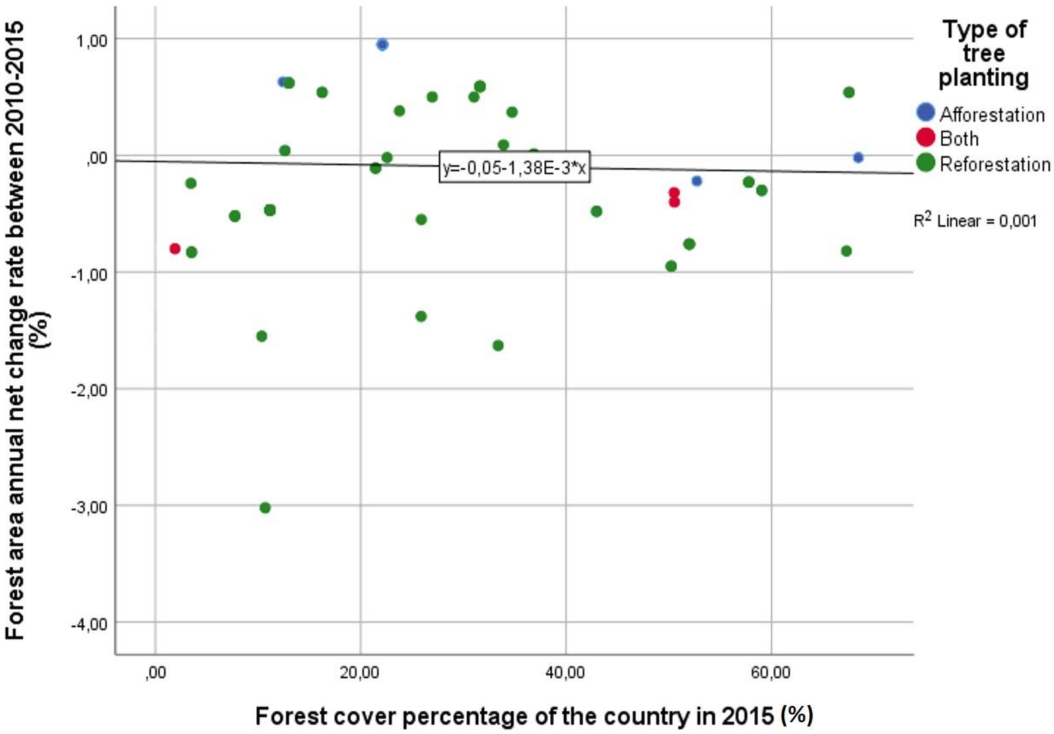

Figure 12. A scatter graph of the forest area annual net change rate between 2010 – 2015 (%) of a country's project site versus forest cover (%) of the country in 2015, (*N* = 36). The forest cover (%) of a country in 2015 data was collected from the webpage by Roser (2013) and was defined as 'land under natural or planted stands of trees of at least 5 meters in situ, whether productive or not, and excludes tree stands in agricultural production systems'. The data for the variable, "forest area annual net change rate between 2010 – 2015 (%)" was sourced under indicator 15.2.1 of United Nations (2020). A linear regression analysis was conducted between the two variables.

Research Question 3: How do tree planting program sites differ in terms of primary or secondary objective (e.g. carbon sequestration) and their key ecological factors?

To address the third research question a relationship between the continental region and the primary objective of a tree planting project was tested (Figure 13). A significant association between the continental region of a tree planting project site and the primary objective of a tree planting project was demonstrated, χ^2 (6) =33.990, p = 0.000. The Cramer's V test indicated there is an association of moderate strength between these two variables ϕc = 0.399, p = 0.000. Project sites for the primary objective of forest restoration are most prominent in Europe, whilst projects for agroforestry are most common in Africa and the projects for production are dominant in Asia & Oceania.

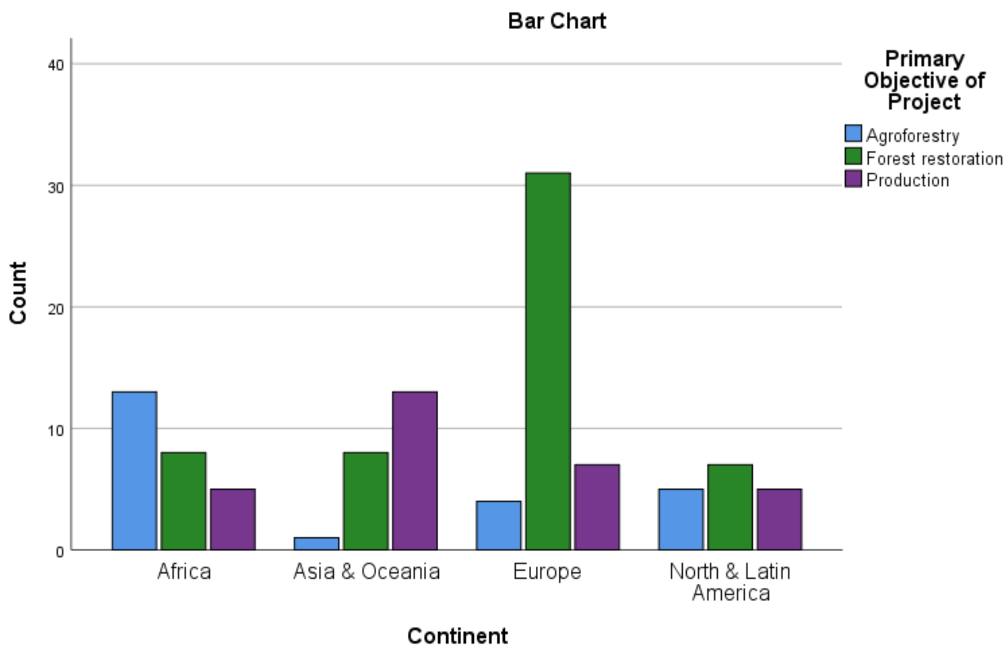

Figure 13. A bar chart of the frequency for different primary objectives of tree planting projects compared across different continental regions ($N = 107$). A chi-square test of independence was conducted ($p < 0.001$). Project sites that were for either local income generation or were for commercial agroforestry were classified as "Agroforestry". The same was done for the case for local income generation production plantations and commercial plantations (including carbon credit generation projects) were labelled under the primary objective, "Production".

Furthermore, Figure 14 demonstrates that numerous project sites that have forest restoration as the primary project objective been mislabelled under the term, "afforestation". This is particularly the case for project sites in North & Latin America as well as Europe, which further demonstrates the misunderstanding of key terms and definitions by tree planting programs. Contrastingly, it was found that the majority of project sites labelled as afforestation in Asia & Oceania as well as Africa are focused on the primary objective of production rather than agroforestry. A larger proportion of projects labelled as reforestation are for the primary objective of forest restoration in Europe and Asia & Oceania, whereas in Africa and North & Latin America there is a larger majority of project sites that are for the main purpose of agroforestry.

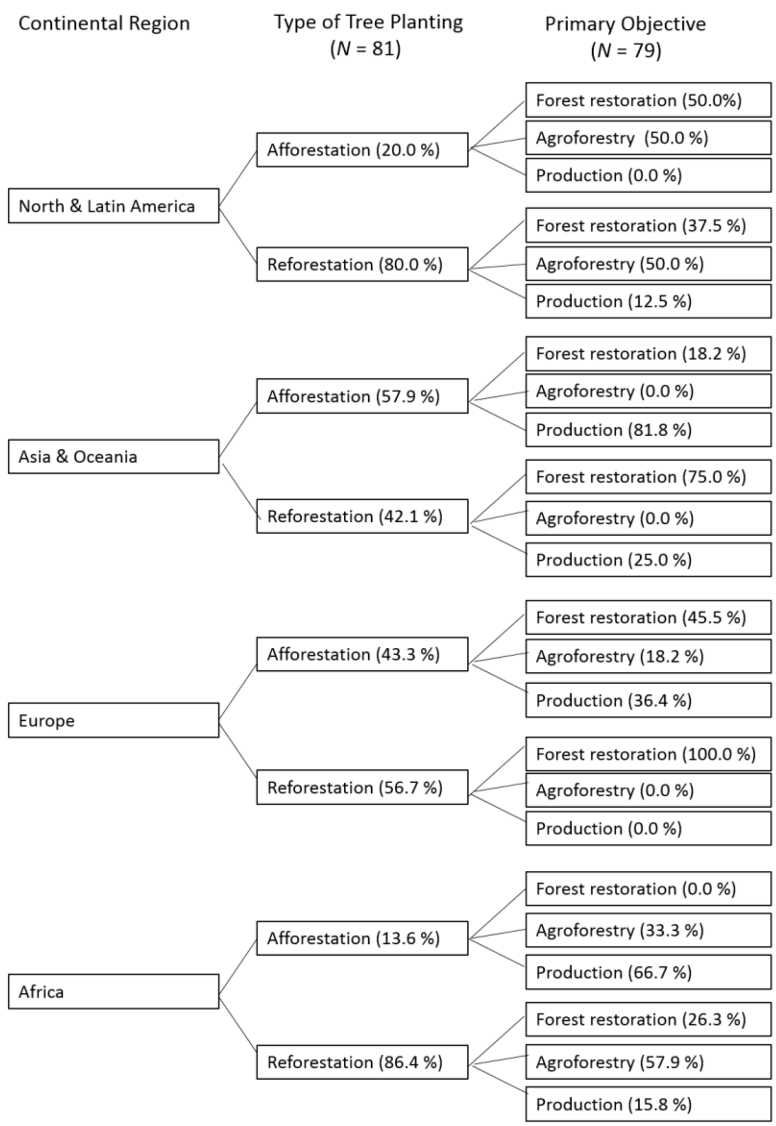

Figure 14. A flowchart from a subset of the data collected demonstrating the proportion of different types of tree planting implemented between different continental regions and the different primary objectives for those specific project sites. Values that were labelled "Both" for type of tree planting were excluded from this subset. Percentages were also rounded to 3 significant figures.

To research further factors that may influence the division between different primary objectives of tree planting projects, the type of terrestrial ecosystem of project sites was statistically analysed against the primary objective of projects (Figure 15). A significant association between the type of terrestrial ecosystem of a tree planting project site and the primary objective of a tree planting project was found, $\chi^2\,(4) = 14.161$, $p = 0.007$. Based on the results of this test, there is a significant but moderate strength of association between these two variables $\phi c = 0.338$, $p = 0.007$. Forest restoration projects are found mostly in the temperate broadleaf and mixed forests ecosystem (Figure 15). There is only a marginal difference between the ecosystem types featuring agroforestry projects, but the greatest proportion of these projects are found in the tropical and subtropical moist broadleaf forests ecosystem whilst projects for production have the highest frequency in the temperate broadleaf and mixed forests ecosystem.

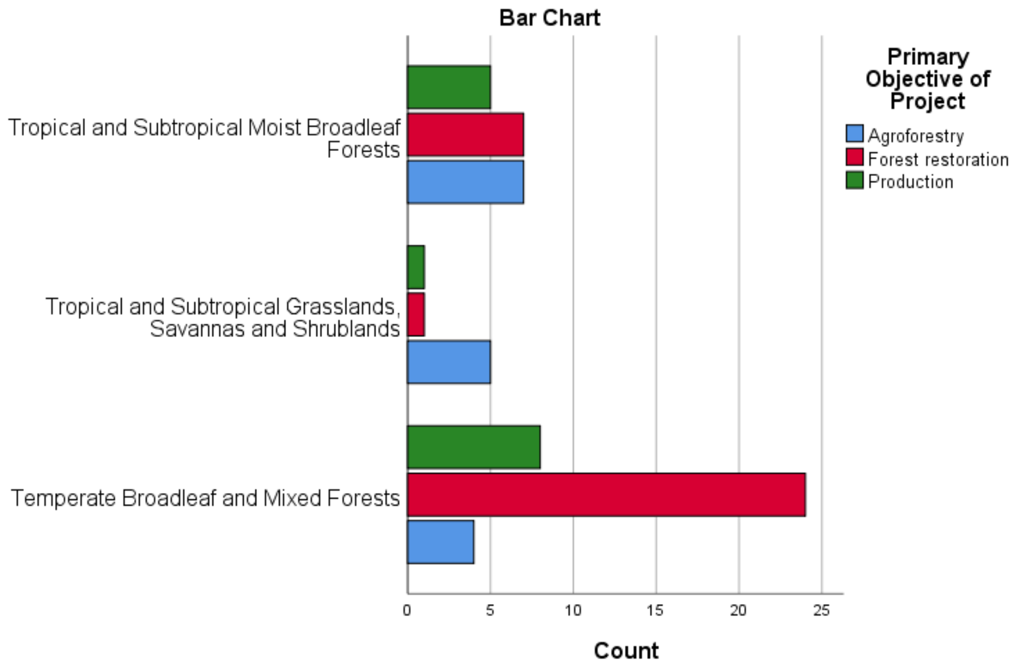

Figure 15. A bar chart of the terrestrial ecosystem of the tree planting project sites compared against the primary objective of the project (N = 62). A chi-square test of independence was conducted ($p < 0.01$).

Unfortunately, the count was too low to conduct a chi-square test of independence between the terrestrial ecosystem of a project site and the secondary objective of a project (Figure 28, Appendix A). However, it was found that a majority of project sites found within the temperate broadleaf and mixed forests ecosystem are for the secondary objective of carbon sequestration, followed by recreation/education (Figure 28, Appendix A). The secondary project objective of biodiversity enhancement/conservation is most prevalent among project sites in the tropical and subtropical moist broadleaf forest ecosystem (Figure 28, Appendix A).

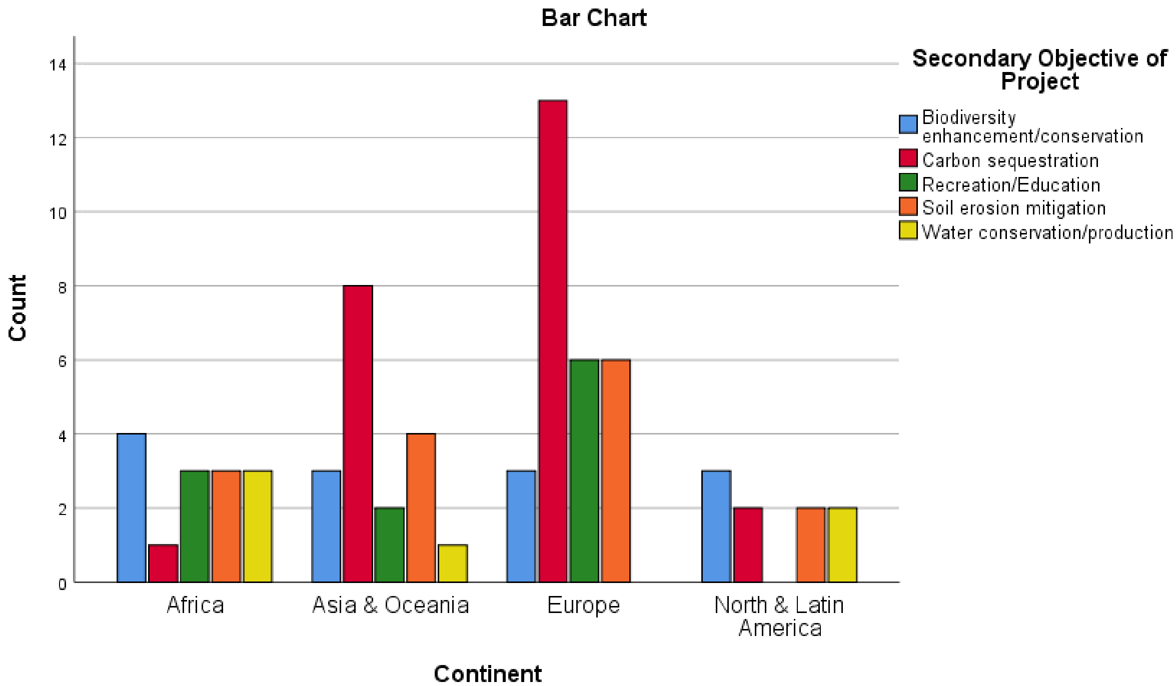

Figure 16. A bar chart of secondary objective of tree planting projects compared between the different continental regions of the project sites, (N = 69). A chi-square test of independence was conducted ($p > 0.05$).

A chi-square test of independence was also conducted for the secondary objective of tree planting projects between different continental regions (Figure 16). However, no significant association was found between the two variables, χ^2 (12) = 17.431, $p = 0.134$. This result of statistical insignificance is likely because of the low counts between variables due to the data availability of the secondary objective and motivations of tree planting projects online. Figure 16 demonstrates that carbon sequestration projects, as well as projects to mitigate soil erosion, have the highest frequency in Europe followed by Asia & Oceania. Water conservation/production as a secondary objective has the lowest frequency throughout the different continental regions.

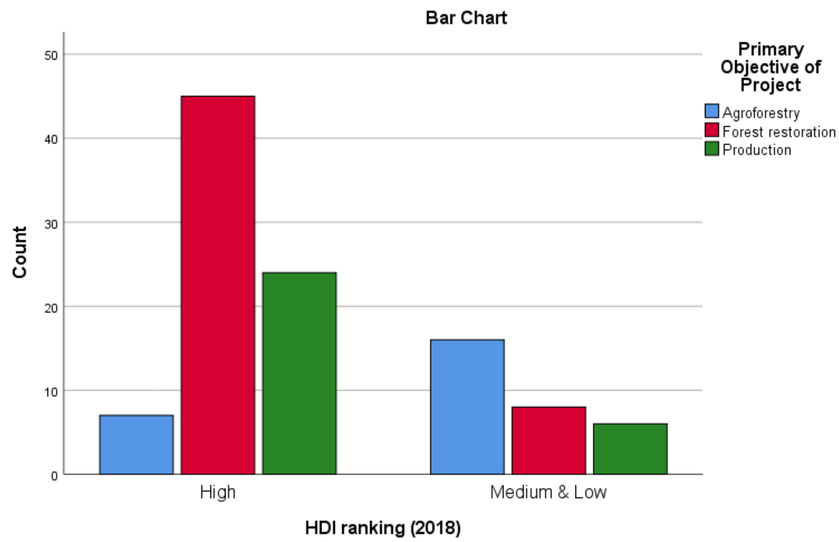

Figure 17. A bar chart comparing the primary objective of tree planting projects against the Human Development Index ranking of the country of the project site's location, N = 106. A chi-square test for independence ($p < 0.01$).

In order to uncover whether there may be a more societal influence on the primary objective of a tree planting project, the ranking of the Human Development Index of the country of the tree planting project site was analysed as a factor. Consequently, a significant association between the HDI ranking of the country of the project site and the primary objective of the tree planting project was observed, $\chi^2(2) = 24.874$, $p = 0.000$. There is also a significant association of moderate strength between these two variables $\phi c = 0.484$, $p = 0.000$. Forest restoration projects are found substantially more in high HDI ranked countries than those ranked medium & low. Additionally, projects for production are found somewhat more in high HDI ranked countries and agroforestry projects are more common in medium & low HDI ranked countries. The testing for an association between the secondary objective of a project & HDI ranking of a project site's country did not display any statistically significant association.

Research Question 3.1: How do tree planting sites differ in key ecological factors such as the composition and type of tree species planted?

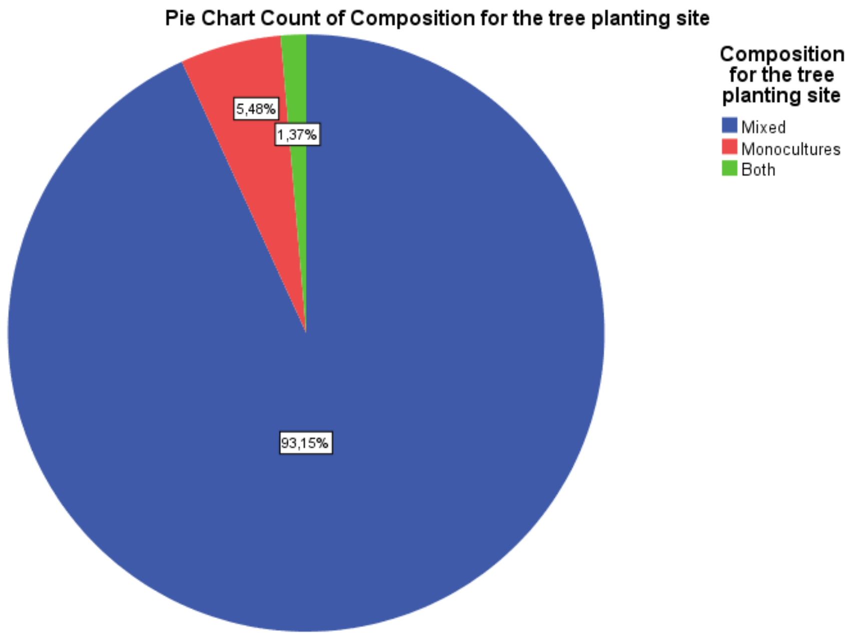

Figure 18. A pie chart of the percentage of different types of composition of tree planting between a subset of project sites, based on data availability (*N* = 73).

Figure 18 shows a much larger majority of project sites (with data on their tree planting composition) is found to feature mixed species planting (93.2%) over planting monocultures (5.5%) or a feature mixture of both on the same project site (1.4%).

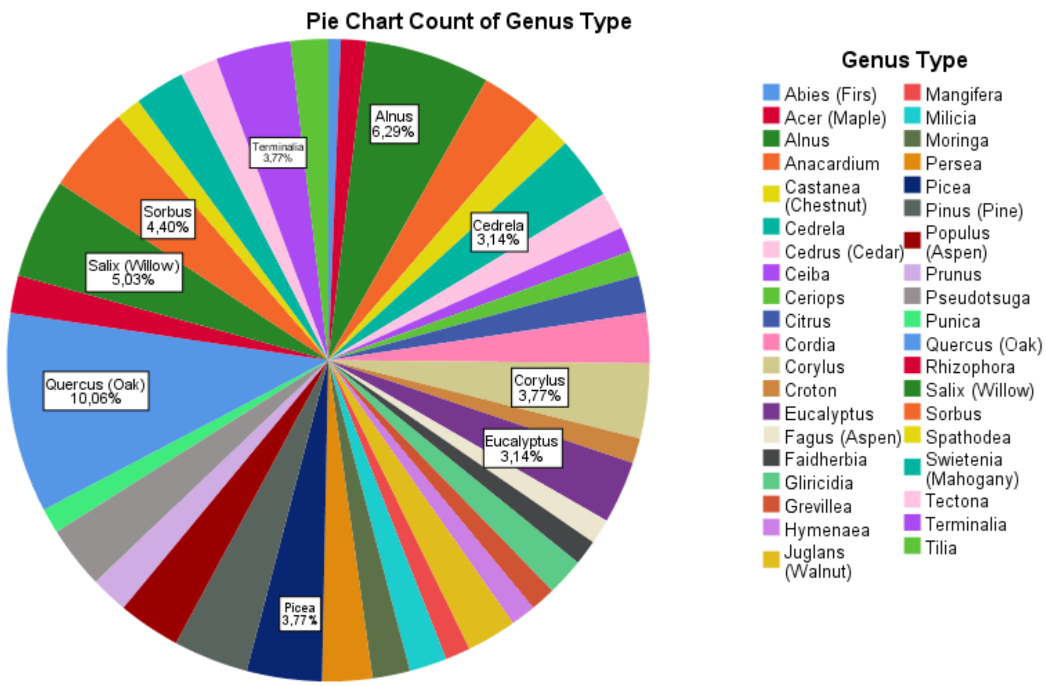

Figure 19. A pie chart of the different genus types of trees planted identified. This included only genus types that had a greater frequency than one count, (*N* = 159).

A large sample of different species of trees planted was collected (Table 6, Appendix A), where the most common featuring genus types on project sites are Quercus (10.1%), Alnus (6.3%) and Salix (5.0%) as shown in Figure 19.

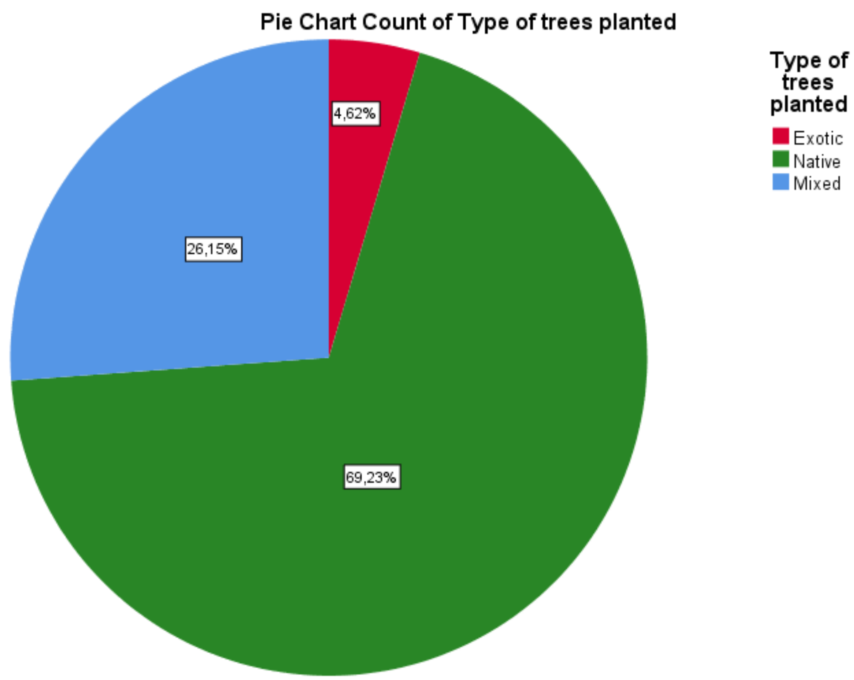

Figure 20. A pie chart of the proportion of different types of trees planted, (N = 65).

Additionally, it is also found that slightly less than 70% of the project sites (with data on tree species type) had claimed to plant only native tree species on their project sites compared to 4.6% that planted only exotic tree species and 26% planted a mix of both exotic and native tree species (Figure 20).

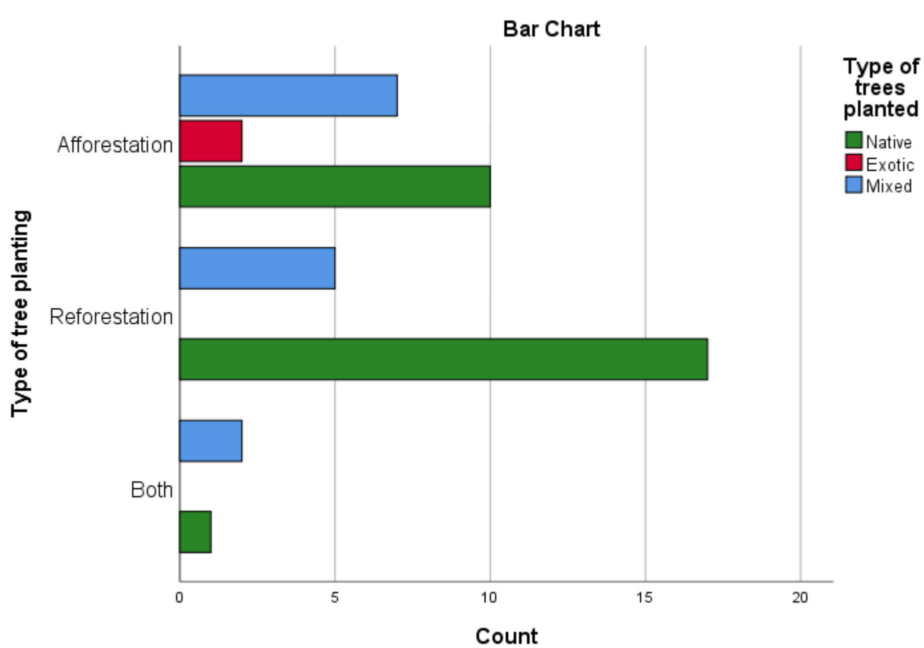

Figure 21. Type of tree species planted compared with the type of tree planting labelled for a project. A significance test was not possible due to the low count (N = 44).

Mixed species planting was most common for afforestation projects, whereas solely native tree species planting was most prevalent for reforestation. However, various project sites mentioned planting solely native tree species for projects labelled afforestation (Figure 21). With the further inspection of the data inventory it was also found that nine of the tree planting project site that claimed to have planted native tree species were found to be located in non-forest terrestrial ecosystems.

Research Question 3.2: How do tree planting program sites differ in the implementation of measures taken and for the monitoring of biodiversity conservation of their respective sites?

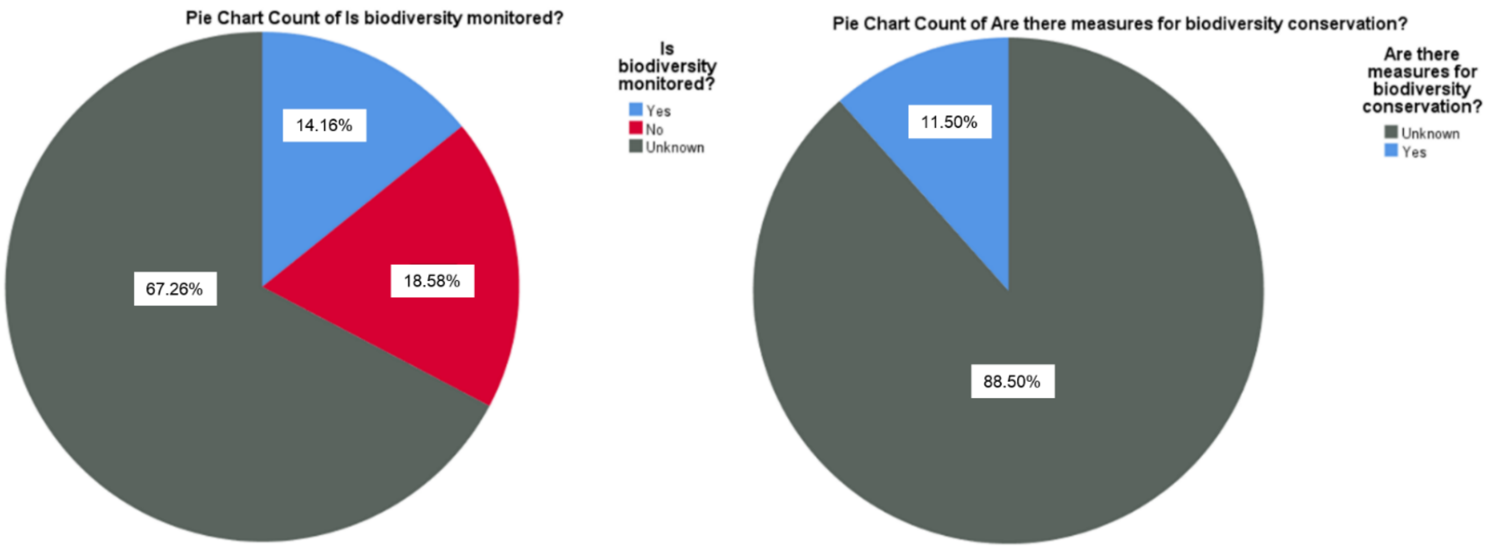

Figure 22a & 22b. Pie charts of tree planting project sites with biodiversity measures or monitoring (*N* = 113).

Only 35% of the 20 tree planting programs explored, explicitly mentioned that they monitored the biodiversity of their tree planting project site(s). Thus, it was found that more project sites explicitly mentioned that they do not have biodiversity monitoring in place (18.6%) than those that do (14.16%). Out of all the projects that have biodiversity monitoring, just under half of them were found to do monitoring once every five years. Despite this, it was found that half of all the programs mentioned on their websites, that their tree planting projects were to improve or conserve biodiversity & wildlife. This included two programs that explicitly stated that they do not monitor biodiversity for their project sites. One tree planting program representative admitted that one of their focus areas as future work was to structure and develop key performance indicators and monitoring framework, to evaluate the progress of increasing biodiversity, for a larger number of their projects (Anonymous Tree Planting Program Representative A, 2020). Furthermore, only a minority of tree planting project sites, 13 out of 113 of the sample have mentioned that they have implemented measures to increase or conserve biodiversity e.g. providing and designing forest corridors to enable connectivity for wildlife.

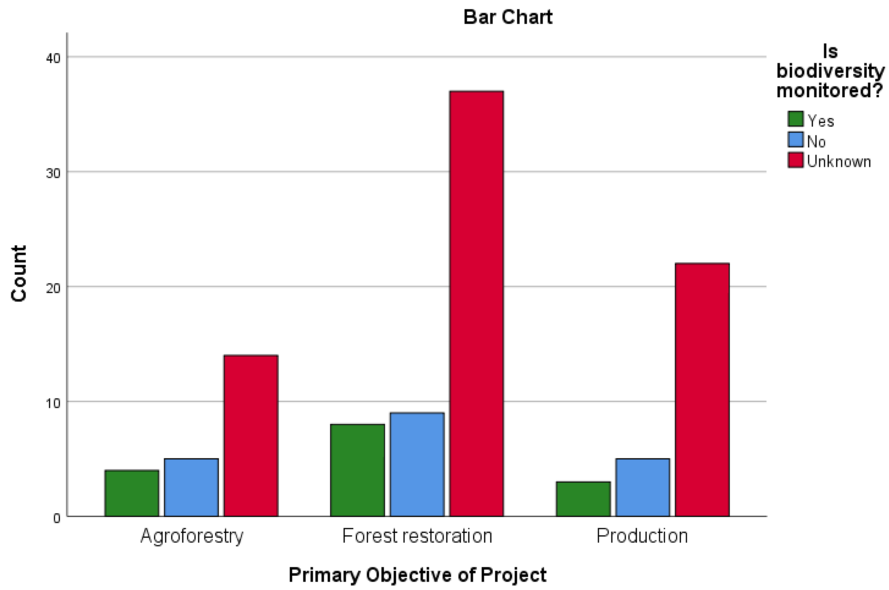

Figure 23. A bar chart analysing whether a project is monitoring biodiversity on the project site in comparison to the primary objective of the project, (*N* = 107).

Probing further into the ratio between project sites that have biodiversity monitoring and those which do not (as well as project sites where it is unknown), it is shown that biodiversity is less likely to be monitored for (regardless of what the primary objective of the project is).

Furthermore, when comparing this ratio to the secondary objective of tree planting projects, only three of the 13 tree project sites with the secondary objective of biodiversity enhancement and conservation are found to monitor biodiversity, whilst four project sites explicitly mentioned that they do not monitor biodiversity, and the rest were unknown (Figure 29, Appendix A).

Research Question 3.3: How do tree planting program sites differ in the implementation of measures taken and for the monitoring of local water management of their respective sites?

Only 13 of the 113 tree planting project sites explicitly mentioned that they had measures for local water management. None of the 113 explicitly mentioned that they did not have measures for local water management. Consequently, it was not possible to conduct statistical tests using this variable.

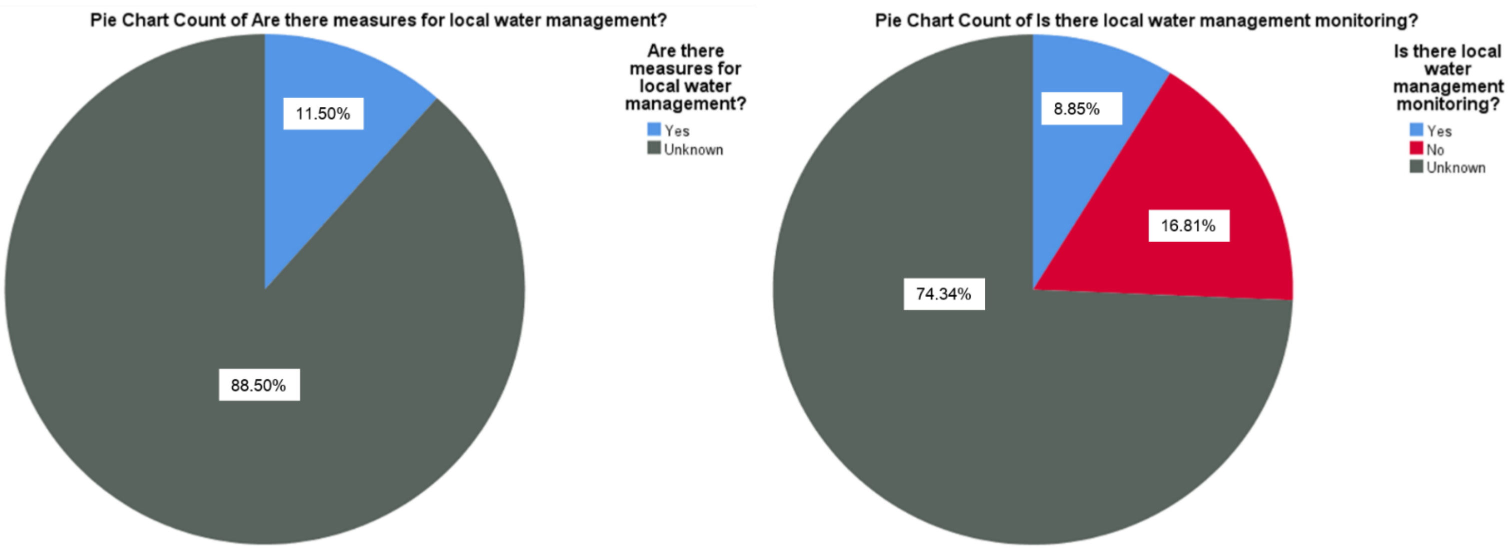

Figure 24a & 24b. Pie charts demonstrating the proportion of tree planting project sites with local water management measures or monitoring in place, (*N* = 113).

More than 10% of tree planting sites mentioned that they had measures for local water management e.g. planting exotic tree species a certain distance from riparian zones. Unfortunately, due to low counts and missing data it was not possible to statistically analyse whether the secondary objective or the terrestrial ecosystem of a project site influenced whether the project site would have a water monitoring plan.

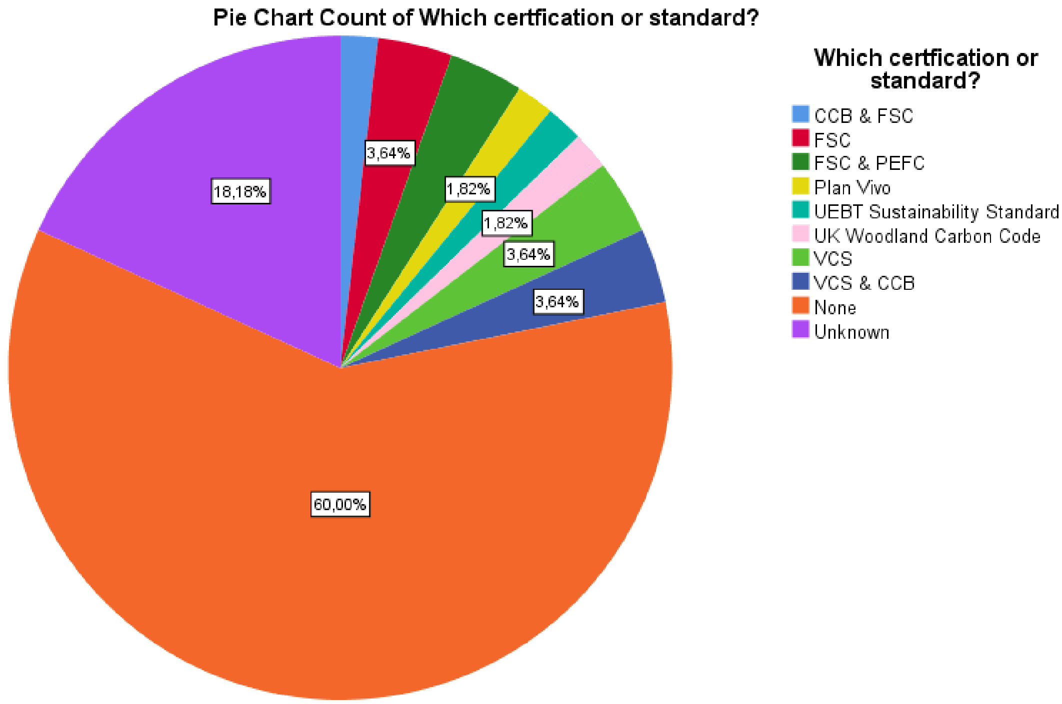

Figure 25. A pie chart of the different certification or standards used for tree planting project sites and the percentage proportion of project sites that use them, (*N* = 55).

To analyse further into what certification standards are verified among the total data sample, a pie chart was created (Figure 25). A vast amount of the project sites within the sample are found to have no verification of any certification standard (60.0%). Of the projects that have a certification or standard, the following are the most used among tree planting project sites; the Forest Stewardship Council (FSC) certification and the combinations of the Verified Carbon Standard (VCS) & the Climate, Community and Biodiversity (CCB) Standards as well as FSC certification & the Programme for the Endorsement of Forest Certification (PEFC) standard. These types of certification and standards are typically used for carbon credit projects or to ensure that wood production is sustainably sourced and originates from a sustainably managed forest.

Discussion

Research Question 1: What are the key ecological variables for best practices of tree planting program sites?

The best practices for tree planting should be judged on the location (geographically, biome type/terrestrial ecosystem type and climatic conditions) and the biophysical conditions of the land itself per situation per project objective basis. However, the findings of literature and from expert interviews have suggested that certain generalized guidelines can be made from a holistic perspective (environmental, economic, societal etc.). The choice of a site must be carefully considered especially for the afforestation of 'degraded land' where appropriate methods should be used to verify the land as degraded and not hosting a pre-existing ecosystem.

However, generally reforestation may be the most appropriate approach to protect and create buffer zones beneficial for the native flora and fauna of the remnants of forest areas needing protection from environmental disturbances. Furthermore, to improve the resilience of forest stands from environmental disturbances it is recommended that a mixture of species are planted rather than a singular species, to also benefit the forest reaching different stages of succession (Ball et al., 1995; Brockerhoff et al., 2008). Although, it is to be noted that the advantage of having mixed species but this is also dependent on the geographical region and forest ecosystem type of a potential project site. For instance boreal forests despite having naturally lower levels of tree species diversity than tropical forests, are quite ecologically resilient and may be more viable for future carbon projects due to changing climate trends (Thompson et al., 2009). However, where tropical forest ecosystems are particularly vulnerable to pressures such as climate change, (as a result risking the loss of many global fauna and flora species) the planting of mixed tree species may help increase their resilience against this pressure (Thompson et al., 2009). As a result these particular findings match to the original hypothesis of this research question.

To mitigate the environmental risks that are posed by introducing exotic tree plantations it is proposed that mechanisms to monitor and prevent negative impacts (e.g. identifying the different stages of invasiveness, where resources are available/affordable), are implemented to check current global exotic plantations (Dodet & Collet, 2012). However, ideally a long term future solution may be finding ways to push up the market value of native and mixed species forests, for instance establishing a native forest with the provision of a variety of valuable co-benefits. Additionally, searching for marketable wood products of native species may also advocate the establishment of native commercial plantations over exotic plantations. Combining these types of approaches in a local landscape would help generate economic revenue that may be vital for landowners, local communities and stakeholders, whilst simultaneously minimizing environmental risks and threats that exotic species may bring (Feyera et al., 2002). However, challenges of capacity building, funding and building more knowledge (e.g. finding native species seeds or propagating them) must first be addressed and further researched before designing and implementing such solutions for best practices of tree planting.

Key Ecological Factor	Key Recommendations for Best Practices
Location	The focus of tree planting should be in forest type ecosystems but especially in tropical forest ecosystems, where biomass productivity rates are high – beneficial for economic production project objectives as well as to fulfil ecological and conservation objectives. Reforesting tropical forest ecosystems may contribute to preserving valuable areas of high biodiversity.
Type of previous land cover	Tree planting projects on land that was historically forest should be the priority for restoration type projects. Afforestation projects are only suitable for land that was accurately measured and determined as degraded (where methods of measuring the abundance of vegetation are not solely used).
Type of tree species planted	It is recommended that native tree species are used for both forest restoration projects but also for production purposes (where opportunities in the market are possible for native tree species wood product alternatives).
Type of tree planting composition	Mixed species planting is the most advantageous approach ecologically as it ensures improved resilience and resistance of the forest ecosystem to disturbances (e.g. pests) but this is dependent on the forest ecosystem type. However, for the harvesting of trees for production purposes, mixed tree species planting may be perceived as impractical.

Table 3. A table of summarized recommendations from the four key ecological factors discussed in the first research question results section.

Despite the general recommendations provided it is important to acknowledge the complexity behind finding the most appropriate practices for tree planting projects. For instance, as mentioned earlier, recommended practices may change depending on the local and geographical context per proposed project site, however this is very subjective between the different priorities of stakeholders involved. Therefore, there will always be trade-offs involved for the implementation of a tree planting project but nevertheless the set up and design of a project should be assessed from a holistic perspective. It may also be possible that other restoration options could be explored depending on the state of degradation, to convert the land to its original ecosystem form using alternative restoration methods e.g. rewilding in grasslands.

Research Question 2: How are tree planting initiatives distributed across the globe?

Reforestation type tree planting projects are implemented and used as an instrument to restore forest land and ecosystem functionality damaged from deforestation (Hua et al., 2016). Therefore, it was hypothesized that there would be considerably more reforestation project sites located in countries that are experiencing higher rates of deforestation or in countries with low forest cover that may be demanding for more forest restoration. Nevertheless, it is shown that reforestation project sites are widely distributed regardless of the net percentage change of a country's forest area (between 2010 to 2015) and its percentage forest cover in 2015 (see Figure 12). This may be explained due to the risks and uncertainties and/or the lack of resources and funding involved or needed to do tree planting in areas where forest ecosystems are badly degraded (Figure 4; Chazdon, 2008). For example, lands that are too degraded and infertile from previous unsustainable harvesting activities will require extensive resources and funding to restore and therefore may be perceived as a risky forest restoration investment (Figure 4; Chazdon, 2008). Whereas, tree planting in countries that have lower levels of deforestation and that are less degraded increases the chances of a tree planting program achieving the guarantees of co-benefits from a project. Therefore, for tree planting project partners that rely on a project generating carbon credits through carbon sequestration, the uncertainties of whether restoration can be achieved may discourage a program from setting up a project site within a particular country (Gren & Aklilu, 2016).

For the distribution of projects in regards to different terrestrial ecosystems, it was unexpected to observe that the majority of projects found within the terrestrial ecosystem of tropical and subtropical grasslands, savannas and shrublands were labelled as "reforestation" (Figure 8). Furthermore, a few more projects are also found within other non-forest ecosystems e.g. deserts and xeric shrublands were also labelled as either "reforestation" or a mix of both "afforestation" and "reforestation" (Table 5, Appendix A). This was unforeseen based on the original hypothesis made. However, this supports evidence that tree planting programs misunderstand the definition of reforestation, supporting the original argument by Bond et al. (2019) that grasslands are overlooked as a valuable ecosystem when there is the exploration of tree planting opportunities. This notion that grass-dominated ecosystems are misunderstood can be further supported where it was found that several project sites are located in non-forest ecosystems claiming to plant native tree species.

Based from the literature it is understandable that a majority of tree planting project sites labelled as reforestation are within the tropical and subtropical moist broadleaf forest ecosystem (as shown in Figure 8), due the fast rates of biomass productivity, ensuring quick economic gains for production or bringing in more neighbouring native species (Brockerhoff et al., 2008). Contrastingly, it was unexpected that several tree planting project sites labelled under "Afforestation" were found within the temperate broadleaf and mixed forests terrestrial ecosystem (Figure 8). This also has indicated the misunderstanding of the term "Afforestation" by tree planting programs, because how can tree planting be afforestation if it is done on land that was historically temperate broadleaf and mixed forests (Veldman et al., 2015). This further iterates that there are misconceptions for the meaning for significant terms in the tree planting/forestry sector.

In terms of the difference between continental regions it is shown that most project sites in Europe were labelled as reforestation projects. Therefore, Figure 11 showing that 50% of the European based projects have degraded forest as the previous land cover of the project site is not too surprising of a result, where the reforestation definition is matched (Veldman et al., 2015). Whereas, it is unexpected that despite Africa having substantially more projects labelled as reforestation the most common type of previous land cover is shown to be degraded land (Figure 11). It may have been the case that the African project sites labelled as "reforestation" in the tropical and subtropical grasslands, savannas and shrublands had also been mistakenly described to have degraded land as the previous land cover of the project sites. Furthermore, only 6 of the 113 project sites were mentioned to have been measured for degradation prior tree planting. Thus, it is likely that the land has been falsely classified as degraded, which brings forward a number of environmental concerns that were mentioned earlier by Bond et al., (2019), Brockerhoff et al. (2008) and Hajdu et al. (2016) for the practices of these tree planting initiatives. Consequently, future research should further explore the extent that degradation is measured by tree planting programs and what type of methodology used (e.g. methods that solely focus on the abundance of vegetation, a poor misjudgement leading to the conversion of grassy type ecosystems). However, in general more transparency is needed by tree planting programs for how they classify their afforestation and reforestation projects to improve their creditability and to provide more clarity for potential future tree planting project partners.

Research Question 3: How do tree planting program sites differ in terms of primary or secondary objective (e.g. carbon sequestration) and their key ecological factors?

It was hypothesized that production would be the most common primary objective across the different continental regions, but it was in fact forest restoration with contributions by a large proportion of European based project sites (Figure 13). This is likely due to the drive for natural forest restoration throughout Europe as a key socio-economic and environmental objective, particularly for natural broad-leaved forests (Zerbe, 2002). This may also be due to the significant proportion of the total sample of tree planting project sites being based in Europe (Figure 7). Whereas, there is a greater focus on production as a primary objective for tree planting in Asia & Oceania. This may be explained by Asia-Pacific experiencing one of the fastest continental growth in production, likely caused by the economic growth in that region (FAO, 2019). Furthermore, China has a significant role in the trading of forest products where it has become the largest producer (as well as consumer) of wood-based panels and paper, along with New Zealand becoming the greatest exporter of industrial roundwood in 2018 (FAO, 2019). There is also shown to be considerably more project sites for the secondary objective of carbon sequestration in Europe and Asia & Oceania compared against Africa. This result as well as the association between the HDI ranking of a project site's country and a project's primary objective indicates that more profitable tree planting project activities (carbon credit generation and wood production) are more disproportionally distributed in higher developed countries (Jindal et al., 2008**;** FAO, 2019). Contrastingly, agroforestry which is seen as a less productive and profitable economic activity that can nevertheless be useful for poverty alleviation as well as to address food security issues, is found to be the focus of tree planting projects in Africa and among low developed (in terms of HDI) countries (Mbow et al., 2014; Safa, 2005). This highlights that there is an economic disparity in the tree planting objectives of project sites between different continental regions and between the development rankings of different countries.

It is also shown that a number of tree planting projects for the primary objective of agroforestry are also found in the terrestrial ecosystem type of tropical and subtropical grasslands, savannas and shrublands (Figure 15). The collection of these findings showing projects to be in non-forest ecosystems are alarming as they strengthen the suggestion that some of the tree planting projects may have undergone the natural conversion of these ecosystems. If this is the case (where the previous land cover was not degraded), the impacts may be truly detrimental for the net carbon storage of the land, the survival of native flora and fauna species from the original ecosystem and for the hydrology of the land (Veldman et al., 2015; Bond et al., 2019; Davidson et al., 2012). Furthermore, these project sites would not adhere to the recommendations of best practices.

Unexpectedly, the recommended practices align with a large majority of the tree planting project sites with regards to tree planting composition and type of tree species planted, where there are substantially more project sites that have planted mixed species and sites that have planted only native tree species (Figure 20). It was assumed that there would be a larger proportion of monoculture project sites, especially for the production type projects as globally most plantations are monocultures, but for this sample the findings show otherwise (Piotto, 2008). The sizable proportion of native tree species planting may also suggest that native tree species are also becoming more viable as profitable marketable products or are being produced now where they originate from. The resulting ratio for the proportion of mixed species tree planting may also be due to different countries' national policy or legal restrictions. For instance, the UK Forestry Standard states that for woodland creation it is required that a maximum of 75% of the land can be allocated to the planting of a single species and a minimum of at least 10% of the land involves other tree species planting (Forestry Commission, 2017). Additionally, it is required that 5% of the land has the planting of native broadleaved trees (Forestry Commission, 2017). Therefore, more research is needed to group and clarify the differences (e.g. in the number of tree species planted and the ratio of native to exotic planting) within the tree planting project sites that mention mixed tree species planting. However, as hypothesized it is shown that exotic species have been planted more for projects labelled as afforestation (than those labelled reforestation), whilst solely native tree species planting occurred more for projects labelled as reforestation (Figure 21). Nonetheless, it was unforeseen that native tree species planting was found to be more dominant for afforestation labelled projects than exotic tree species. Although, it appears contradictory that native tree species can be planted for projects labelled as afforestation, where there is tree planting on land that did not historically feature forestry (Veldman et al., 2015). Nevertheless, there may be two reasons for this finding, 1) the project sites that mention only native tree planting are likely to have been mistakenly labelled as afforestation type projects 2) the native tree species planted for these projects may be classified as generalist tree species (and not specialist tree species) that can feature in more than one habitat and can be attractive to specialist and generalist fauna (WWF, 2019a; McConkey & Brockelman, 2011). Thus, if generalist native tree species have been planted, these project sites may be beneficial to enhancing the local biodiversity of the area. Although, it can be noted that the term "native tree species" may also be interpreted very differently between tree planting programs themselves (e.g. based on a specific geographical range and a referenced time frame). For instance one program defined native tree species, to be 'anything that existed before human intervention…irrespective of how long it has been with us' (Anonymous Tree Planting Program Representative B, 2020). Therefore, this may have also affected this particular outcome.

Correspondingly, with the sizable number of project sites that show to have prioritized mixed species planting and solely native tree species planting, as recommended for the best ecological practices (addressed in the first research question), it may have been expected that a majority of project sites would then also feature measures or monitoring for biodiversity, but this is shown to be not the case (Figure 22a & 22b). Furthermore, it was hypothesized that project sites for the secondary objective of biodiversity enhancement and conservation would have monitoring for biodiversity substantially more so than not. Thus, it was a surprising result to see that the opposite is shown where the specific project sites with this secondary objective (and for project sites with forest restoration as their primary objective) are much less likely to have monitoring in place than sites that do (Figure 29, Appendix A; Figure 23). However, one of the tree planting programs mentioned that although they do not have biodiversity monitoring plans in place sometimes tree planting project partners do conduct their own monitoring for biodiversity on their project site(s) (Anonymous Tree Planting Program Representative C, 2020).

A similar trend is shown for the amount of tree planting projects that do local water management compared to those that do not, where there is a much larger proportion of project sites that have no monitoring plan in place than those which do. However, due to the small sample of data available for this variable it was not possible to test the hypothesis that expected to see a difference in water management measures and monitoring between different terrestrial ecosystems. The reason for a disproportionally greater number of tree planting project sites without monitoring in place, for both biodiversity and local water management, may be due to the high costs and resources needed to implement such measures (Azaele et al., 2015; Watson & Novelly, 2004). It may also be the case that monitoring for water management and/or biodiversity was not explicitly mentioned as these measures are already required as part of the verified certification or standard used for a project site. Therefore, it is recommended that future studies could investigate these particular trends against the requirements of certification and standards used.

Nonetheless, based on these results it is clear that there is greater urgency for improved transparency and accountability by tree planting programs, for them to prove the claims they advertise (e.g. the enhancing or preserving of biodiversity) and especially for the programs that emphasize that their project sites are for the secondary objective of biodiversity enhancement/conservation or water production/conservation.

Limitations

One of the key limitations of this independent research study was the application of the proposed data collection methods. Unfortunately, it was challenging to identify and contact tree planting programs that were directly connected to multinational corporations. At times different connections were used to find tree planting programs, for example a large majority of programs were based in Europe, but only partially contributed due to the benefits of utilizing contacts within the WWF network. Moreover, where tree planting programs could be objectively identified it was usually difficult to obtain materials on their tree planting projects e.g. monitoring plans that were publicly accessible. Consequently, this meant there was missing data within the inventory data set for some of the variables. Additionally, as the data collection period was during summer difficulties arose when representatives of tree planting programs were engaged or unavailable due to periods of vacation. Where data was difficult to collect, additional tools such as online public databases were used to gather extra findings. In addition, from the data that was collected it was found that there was an uneven distribution of project sites per tree planting program, this may have created bias and influenced the results of this study (Table 4, Appendix A). Therefore, if time is less constrained and more resources are available, it is recommended that future studies follow more closely to the original proposed methodology, to control the selection of tree planting programs and project sites under investigation. It is also important to take into account that some tree planting programs may have different interpretations of key terms, concepts definitions. Unfortunately it was difficult to clarify how each term is defined by the point of view of programs e.g. native tree species. Therefore, the definitions of terms and concepts may have been unknowingly inconsistently used throughout the inventory of data collected for this research project.

Conclusion

Based from the findings of this research project, there are few highlighted trends that demonstrate efforts of recommended ecological best practices implemented by tree planting programs on their respective project sites. This can be exemplified by the variables of tree planting composition, as well as the type of tree species planted, where a great majority of the project sites in this study reported to plant mainly mixed and native tree species. This has suggested tree planting programs are working towards improving the flora biodiversity of the forests planted, whilst ensuring stability and resilience of the forest ecosystem as it grows through the process of forest succession. However, it is recommended that tree planting projects could further improve the resilience of their tree stands planted if the native tree species type is more carefully selected on the basis of its resilience to projected climate change trends, especially if a project site's primary objective is carbon sequestration to generate credits.

However another key element shown by this study is the misunderstanding of non-forest ecosystems along with the terms, "reforestation" and "afforestation" by tree planting programs. Therefore, natural non-forest ecosystems such as grasslands require further recognition in policy and governance to ensure that the variety of ecosystem services and the carbon sequestration potential they can provide are known as other types of nature based solutions or landscape restoration. Furthermore, based from the tree planting project sites sampled the need for better transparency and verification of biodiversity measures and monitoring requires improvement for programs to be able to contribute towards global biodiversity targets and goals (e.g. Aichi targets).

Consequently, tree planting projects can be found to be effective to a certain degree as a nature based solution in providing carbon sequestration (on appropriately measured and classified land and location) and can help support biodiversity conservation efforts of forest ecosystems. However, as this study has shown the fast implementation of project sites as a "quick-fix" has meant that the development of such key measures and monitoring (such as for biodiversity and local water management), has lacked priority alongside the primary objective of projects to guarantee and verify projects as an effective solution. Therefore, further research is required on the practices of current tree planting programs located globally with a greater sized data sample.

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Appendix A

Program Number	Country of Program' HQ	No. of project sites within program	No. of different countries project sites
1	The Netherlands	2	1
2	The Netherlands	5	2
3	The Netherlands	15	5
4	The Netherlands	4	4
5	The Netherlands	2	1
6	The Netherlands	1	1
7	Brazil	1	1
8	China	1	1
9	Brazil	4	1
10	Portugal	1	1
11	United States	2	2
12	Japan	1	1
13	The Netherlands	21	8
14	Germany	17	16
15	Pakistan	1	1
16	United Kingdom	1	1
17	United Kingdom	1	1
18	China	1	1
19	United Kingdom	5	1
20	France	24	19

Table 4. Information on the tree planting programs that were used during data collection on project sites, *N* = 110. There are three project sites of the total one hundred thirteen project sites (data points) that were forwarded by interviewees that did not specify a key stakeholder or project partner whom was responsible for the tree planting project among the project's site details, which is why the sample size is not one hundred thirteen.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	**Data point/Tree Planting project site**	**Tree Planting Program**	**Country of Tree Planting site**	**HDI of country site (2018)**	**HDI ranking (2018)**	**Continental Region**	**Geographical Region**	**Terrestrial Ecosystem Grouped (excludes Other category)**	**Type of location of the site (e.g. middle of the city/urban environment or outside the city)**	**Type of key stakeholder**	**Role of key stakeholder**	**Certification or Standard achieved?**	**Which certfication or Standard?**	**Forest cover percentage of the country in 2015**	**Forest area annual net change rate between 2010-2015 (%)**	**Previous land cover**	**Previous land use of site**
2	1	1	the Netherland	0.933	High	Europe	Western Europe	Temperate Broadleaf and Mixed Forests		Government Funded	Implementer & financial aider			11.16	-0.47	Pasture land	
3	2	1	the Netherland	0.933	High	Europe	Western Europe	Temperate Broadleaf and Mixed Forests		Government Funded	Implementer & finanancial aider			11.16	-0.47	Pasture land	
4	3	2	Ghana	0.596	Medium	Africa	West Africa	Tropical and Subtropical Moist Broadleaf Forests	Forest area	Private sector	Implementer & monitoring management			41.03	-0.16	Degraded forest	
5	4	2	Tanzania (Unit	0.528	Low	Africa	Eastern Africa	Tropical and Subtropical Grasslands, Savannas and Shrublands	Forest area	Private sector	Implementer & monitoring management	Yes	UEBT Sustainability Standard	52	-0.76	Degraded forest	
6	5	2	Ghana	0.596	Medium	Africa	West Africa	Tropical and Subtropical Grasslands, Savannas and Shrublands		Private sector	Implementer & monitoring management			41.03	-0.16	Degraded land	Agriculture
7	6	2	Ghana	0.596	Medium	Africa	West Africa	Tropical and Subtropical Grasslands, Savannas and Shrublands		Private sector	Implementor & monitoring management	Yes	VCS	41.03	-0.16	Degraded land	Agriculture
8	7	2	Tanzania (Unit	0.528	Low	Africa	Eastern Africa	Tropical and Subtropical Moist Broadleaf Forests		Private sector	Implementor, monitoring management & financial aider			52	-0.76		
9	8	3	the Netherland	0.933	High	Europe	Western Europe	Temperate Broadleaf and Mixed Forests		NGO	Financial aider	No	None	11.16	-0.47		
10	9	3	the Netherland	0.933	High	Europe	Western Europe	Temperate Broadleaf and Mixed Forests	Polder	NGO	Financial aider	No	None	11.16	-0.47		
11	10	3	the Netherland	0.933	High	Europe	Western Europe	Temperate Broadleaf and Mixed Forests	Polder	NGO	Financial aider	No	None	11.16	-0.47		
12	11	3	the Netherland	0.933	High	Europe	Western Europe	Temperate Broadleaf and Mixed Forests		NGO	Financial aider	No	None	11.16	-0.47		
13	12	3	Malaysia	0.804	High	Asia & Oceania	Southeast Asia	Tropical and Subtropical Moist Broadleaf Forests		NGO	Financial aider			67.55	0.54		
14	13	3	Philippines	0.712	High	Asia & Oceania	Southeast Asia	Tropical and Subtropical Moist Broadleaf Forests		NGO	Financial aider			26.36	0.5		

	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
1	**Measured or monitored for degradation?**	**Symptoms of degradation identified? (e.g. lots of bare soil, signs of erosion, vegetation**	**Type of tree planting (Reforestation or Afforestation or Both)**	**Primary Objective of Project**	**Secondary Objective of Project**	**A carbon credits project?**	**Composition for the tree planting site (Mixed/Monocultures/Both)**	**Type of trees planted (Native/Exotic/Mixed)**	**Number of tree species planted on the site**	**Carbon sequestration of the site measured?**	**Frequency of measuring carbon sequestration**	**Are there measures for biodiversity conservation? (Yes/No/Unknown = Blank)**	**Is biodiversity monitored? (Yes/No/Unknown = Blank)**	**Frequency of monitoring biodiversity (flora and fauna)**	**Water management measures? (Yes/No/Unknown = Blank)**	**Water management monitoring? (Yes/No/Unknown = Blank)**	**Frequency of monitoring for water conservation of the site**
2			Afforestation	Forest restoration	Biodiversity enhancement/conservation	No	Mixed	Native	36	Yes		Yes	Yes	Monthly	Yes	Yes	
3			Afforestation	Forest restoration	Biodiversity enhancement/conservation	No	Mixed	Native	6	Yes		Yes	Yes	Monthly	Yes	Yes	
4	Yes		Reforestation	Agroforestry		No		Native					Yes	Every 5 years		Yes	
5	Yes		Reforestation	Agroforestry		No		Native				Yes	Yes	Every 5 years		Yes	
6			Reforestation	Forest restoration		No	Mixed	Native	23			Yes	Yes	Every 5 years	Yes	Yes	Seasonal
7			Reforestation	Production		No	Mixed	Mixed	1	Yes		Yes	Yes	Every 5 years	Yes	Yes	Seasonal
8			Afforestation	Production		No	Mixed	Mixed	24	Yes	Annual	Yes	Yes	Every 5 years	Yes	Yes	Daily to Annual
9			Afforestation	Forest restoration		No	Mixed	Native								No	
10				Forest restoration		No	Mixed	Native				Yes				No	
11				Forest restoration	Recreation/Education	No	Mixed	Native								No	
12				Forest restoration	Recreation/Education	No	Mixed	Native								No	
13			Reforestation	Forest restoration		No		Native		Yes						No	
14			Reforestation	Forest restoration		No	Mixed	Native								No	
15				Production		No		Native								No	

Figure 26a & 26b. Screenshots of the inventory used to collect data on different tree planting project sites and programs. Data was collected for different categories of variables as shown here to identify similarities & differences between different individual tree planting program project sites.

Research Question 2: How are tree planting initiatives distributed across the globe?

Terrestrial Ecosystem	Count of labelled Afforestation project sites	Count of labelled Reforestation project sites	Count of labelled Afforestation & Reforestation project sites (Both)	Afforestation termed sites, percentage of the total (%)	Reforestation termed sites, percentage of the total (%)	Afforestation & Reforestation (Both) labelled sites percentage of the total (%)	Total percentage (%)
Tropical and Subtropical Moist Broadleaf Forests	1	13	1	1.7	22.4	1.7	25.9
Tropical and Subtropical Grasslands, Savannas and Shrublands	1	5	0	1.7	8.6	0.0	10.3
Temperate Broadleaf and Mixed Forests	14	11	1	24.1	19.0	1.7	44.8
Tropical and Subtropical Dry Broadleaf Forests	0	1	0	0	1.7	0	1.7
Mediterranean Forests, Woodlands and Scrub	0	3	0	0.0	5.2	0.0	5.2
Deserts and Xeric Shrublands	1	0	1	1.7	0.0	1.7	3.4
Mediterranean Forests, Woodlands and Scrub & Deserts and Xeric Shrublands	0	1	0	0.0	1.7	0.0	1.7
Mediterranean Forests, Woodlands and Scrub & Temperate Broadleaf and Mixed Forests	0	1	0	0.0	1.7	0.0	1.7
Tropical and Subtropical Grasslands, Savannas and Shrublands & Tropical and Subtropical Moist Broadleaf Forests	0	1	0	0.0	1.7	0.0	1.7
Tropical and Subtropical Grasslands, Savannas and Shrublands & Montane Grasslands and Shrublands	0	1	0	0.0	1.7	0.0	1.7
Tropical and Subtropical Moist Broadleaf Forests & Montane Grasslands and Shrublands	0	1	0	0.0	1.7	0.0	1.7

Table 5. This table presents the count data of project sites described as afforestation, reforestation or a mixture of both types for each terrestrial ecosystem determined. This table includes the data of seven more (grouped) terrestrial ecosystems, e.g. Deserts and Xeric Shrublands and Tropical and Subtropical Dry Broadleaf Forests which were excluded for the chi-square test of independence due to their low count numbers.

Species List	Count
Acacia abyssinica	1
Acacia lehai	1
Acacia mangium	1
Acacia melifera	1
Acacia Nilotica N	1
Acacia polyacantha	1
Acacia senegal.	1
Acacia xanthophloea	1
Acer campestre (Field maple)	2
Acrocarpus fraxinifolius (Pink Cedar)	1
Acrocomia aculeata	1
Adansonia digitata (Baobab)	1
Aegiceras corniculatum	1
Aegiphila integrifolia	1
Afrocarpus falcatus (African pine tree)	1
Afzelia africana (Papao)	1
Albizia carbonaria	1
Albizia ferruginea (Awiemfosemina)	1
Albizia gummifera	1
Albizia zygia (Okoro)	1
Alchornea sidifolia	1
Allanblackia parviflora	1
Allanblackia Stuhlmannii	1
Alnus acuminata	1
Alnus glutinosa (Black Alder)	7
Alnus indicana (Grey Alder)	1
Anacardium occidentale (Cashew)	5
Aningeria altissima (Asanfena)	1
Arbustus unedo (Strawberry)	1
Archidendron pauciflorum	1
Argania spinosa	1
Artocarpus heterophyllus	1
Aspidosperma macrocarpon	1
Avicennia marina	1
Bactris gasipaes (Peach Palm)	1
Bertholletia excelsa (Brazilian Walnut)	1
Betula pendula (Silver Birch)	1
Betula pubescens (Downy Birch)	1
Bixa orellana (Roucou)	1
Blighia sapida (Akyei)	1
Brachylaena huillensis	1

Bridelia micrantha	1
Brosimum alicastrum (Mayan walnut)	1
Bruguiera gymnoohiza	1
Calophyllum brasiliense	1
Calycophyllum spruceanum	1
Carapa guianensis (Andiroba)	1
Carpinus betulus (Hornbeam)	1
Cassia sena	1
Castanea sativa	3
Cedrala molinensis	1
Cedrela fissilis	1
Cedrela odorata (Spanish cedar)	4
Ceiba pentandra (Onyina)	2
Celtis africana	1
Centrolobium tomentosum	1
Ceratonia siliqua	1
Ceriops tagal	2
Chamaecyparis pisifera (Sawara cypress)	1
Chrysophyllum albidum	1
Cinnamomum camphora (camphor)	1
Citrus × sinensis (Sweet Orange)	3
Citrus limon (Lemon)	3
Citrus reticulata (Mandarin orange)	1
Clerodendrum heterophyllum	1
Combretum molle	1
Combretum zeyheri	1
Cordia africana	4
Cordia alliodora	2
Cordia millenii (Tweneboa)	1
Corokia whiteana	1
Corylus avellana (Hazel)	6
Crataegus laevigata (Midland Hawthorn)	1
Crataegus monogyna (Common Hawthorn)	1
Crataegus succulenta (Jubilee)	1
Cristobal montano	1
Croton macrostachyus	2
Croton mauritianus	1
Cydonia oblonga (Quince)	1
Davidsonia johnsonii	1
Desmodium acanthocladu	1
Detarium guineense (Takyikyiroa (Mambode))	1
Dialium guianense	1

Diospyros mespiliformis (Ebony)	1
Diploglottis campbellii	1
Dipteryx odorata	1
Dombeya populnea	1
Dombeya rotundifolia	1
Doryanthes palmeri	1
Drynaria rigidula	1
Erythrina abyssinica	1
Erythrophleum suavolens (Potrodum)	1
Erythroxylum hypericifolium	1
Escallonia resinosa	1
Eucalyptus grandis x Eucalyptus camaldulensis	1
Eucalyptus grandis x Eucalyptus tereticornis	1
Eucalyptus grandis x Eucalyptus urophylla	1
Eucalyptus saligna (Sydney Blue gum)	1
Euonymus europaeus (European Spindle)	1
Euterpe edulis	1
Euterpe oleracea (Acai)	1
Fagus sylvatica (Birch)	2
Faidherbia albida	2
Ficus natalensis	1
Foetidia mauritiana	1
Fraxinus excelsior (Ash)	1
Fraxinus ornus (Ebben's Column)	1
Funtumia elastica	1
Garcinia kola (Small cola)	1
Gliricidia sepium	3
Glochidion ferdinandi (Cheese tree)	1
Gmelina arborea (Kumil)	1
Grevillea robusta (Grevillea)	2
Guarea rugby	1
Hibiscus columnaris	1
Hura crepitans	1
Hymenaea courbaril	3
Ilex aquifolium (Holly)	1
Indigofera ammoxylum (DC.) Polhill (Sandwood)	1
Inga spectabilis	1
Intsia bijuga (Pacific Teak)	1
Jatropha curcas L.	1
Juglans neotropica	1
Juglans regia	1
Juniperus oxycedrus	1

Juniperus phoenicea	1
Khaya anthotheca	1
Khaya senegalensis	1
Limonia acidissima	1
Lomatia hirsuta (Nogal silvestre)	1
Maesopsis eminii	1
Malus baccata (Street Parade)	1
Malus domestica (Apple)	1
Malus sylvestris (European Crab Apple)	1
Malus toringo (Scarlett)	1
Mangifera indica L. (Mango)	2
Mansonia altissima (Oprono)	1
Markhamia lutea (Nile Tulip)	1
Melia Dubia (Malai Vembu)	1
Mespilus germanica (Medlar)	1
Milettia ferruginea	1
Milicia excelsa (Odum)	3
Mimusops bagshawei	1
Mitragyna stipulosa	1
Moringa oleifera	3
Obetia ficifolia (Nettle wood)	1
Olea europea	2
Parkia biglobosa (Dawadawa)	1
Parkia bilobosa	1
Parkia javanica	1
Parkinsonia aculeata	1
Parrotia persica	1
Pentaclethra macroloba	1
Pericopsis elata (Kokrodua)	1
Persea americana (Avocado)	4
Philenoptera violacea	1
Phyllanthus emblica	1
Picea abies (Norway Spruce)	3
Picea sitchensis (Sitka Spruce)	3
Piliostigma thonningii	1
Pinus caribaea (Pine)	1
Pinus coulteri D. Don (Coulter pine)	1
Pinus halepensis	1
Pinus monticola (Silver pine)	1
Pinus nigra (Black pine)	1
Pinus pinaster (Maritime pine)	1
Pinus resinosa (Red pine)	1

Pinus sylvestris (Scots Pine)	4
Polygonum persicaria	1
Polylepis racemosa	1
Populus nigra (Black poplar)	1
Populus tremula (Aspen)	1
Posoqueria latifolia	1
Poupartia borbonica J.F. Gmel	1
Prunus amygdales	1
Prunus armeniaca (Apricot)	1
Prunus avium (Sweet cherry)	3
Prunus avlum (Wild cherry)	1
Prunus spinosa (Blackthorn)	1
Pseudotsuga menziesii (Douglas Fir)	5
Psidium guajava (Guava)	1
Pterocarpus erinaceus (Rosewood)	1
Pterocarpus marsupium (Vengai)	1
Pterocarpus santalinus (Red Sandalwood)	1
Punica granatum (Pomegranate)	2
Pyrus communis (European Pear)	1
Quassia amara	1
Quercus alba	1
Quercus coccifera	1
Quercus faginea (Portugeuse Oak)	1
Quercus grisea (Grey Oak)	1
Quercus humboldtii	1
Quercus ilex	1
Quercus nigra	1
Quercus petraea (Sessile Oak)	2
Quercus pubescent (Pubescent/downy oak)	1
Quercus pyrenaica (Pyrenean oak)	1
Quercus robur (Common Oak)	9
Quercus rubra	1
Retrophyllum rospigliosii	1
Rhamnus catharticus (Common Buckthorn)	1
Rhamnus frangula (Alder Buckthorn)	1
Rhamnus lycioides	1
Rhizophora Apiculata	1
Rhizophora mucronata	3
Rhizophora Stylosa	1
Ricinodendron heudelotii (Akpi)	1
Ruizia cordata (White sweetwood)	1
Salix alba (White willow)	1

Salix aurita (Eared Willow)	1
Salix caprea (Goat Willow)	1
Salix cinerea (Grey Willow)	6
Salix daphnoldes (European Violet Willow)	1
Salix fragilis (Brittle willow)	1
Salix humboldtiana (Humboldt's willow)	1
Salix pentandra (Bay Willow)	1
Salix purpurea (Purple Willow)	1
Salix triandra (Almond Willow)	1
Salix viminalis (Osier)	1
Sapium ellipticum	1
Schinus terebinthifolia	1
Schizolobium parahyba (Brazilian fern tree, guapuruvu)	1
Schlizobium amazonicum	1
Senna spectabilis	1
Sesbania Sesban	1
Solanum betaceum (Tamarillo)	1
Sorbus aucuparia (Mountain-ash)	7
Spathodea campanulata	2
Stillingia lineata (Lam.) Müll.Arg. (Tanguin country)	1
Stryphnodendron purpureum	1
Swietenia macrophylla	4
Syzygium cumini	1
Tabebuia impetiginosa	1
Tabebuia ochracea	1
Tabebuia rosea	1
Talbotiella gentii (Takorowanini)	1
Tapirira guianensis	1
Taxus baccata (Yew tree)	1
Tectona grandis (Teak)	3
Terminalia amazonica	1
Terminalia ivorensis (Emire)	3
Terminalia oblonga	1
Terminalia superba (Ofram)	3
Theobroma cacao	1
Theobroma grandiflorum (cupuaçu)	1
Thevetia peruviana (Yellow Laurel)	1
Tilia cordata (small-leaved lime)	2
Tilia platyphyllos (Large leaved Linden)	2
Triplochiton scleroxylon (Wawa)	1
Ulmus glabra (Wych elm)	1
Ulmus laevis (European White Elm)	1

Uvariopsis congensis	1
Virola flexuasa	1
Vitellaria paradoxa (Shea)	1
Vitex keniensis (Meru oak)	1
Warburgia ugandensis	1
Ziziphus mauritiana	1
Zygia longifolia	1
Total Sample Size	354

Table 6. The total sample size of the species & genus mentioned for different tree planting projects, *N* = 419 (including genus separately identified during data collection).

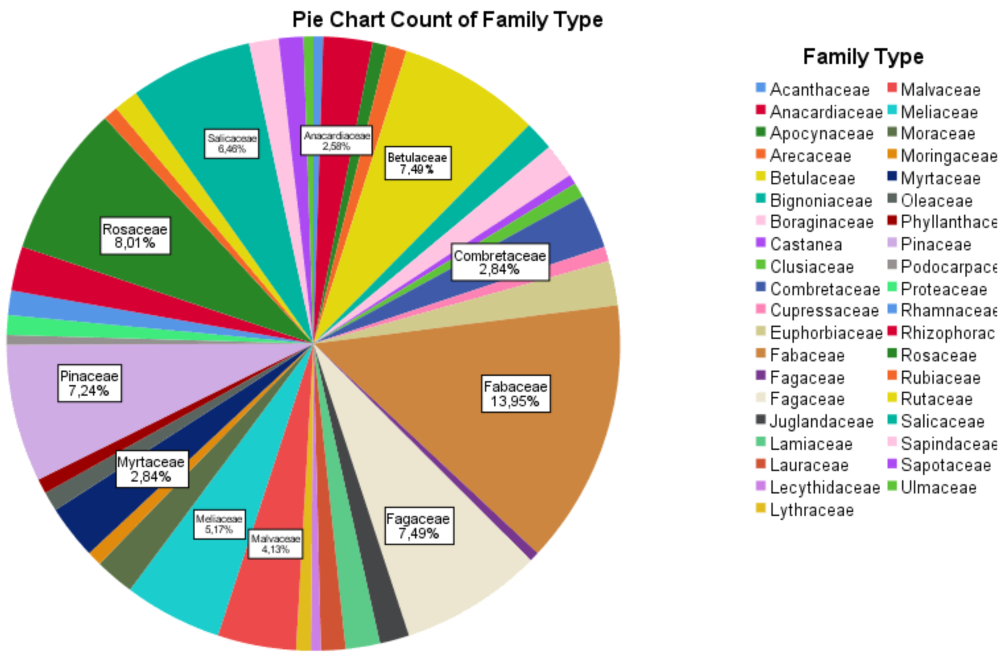

Figure 27. A pie chart of the different family types of trees planted. The category "other" (family types that only featured as one count) and unknown family names data points were excluded from this pie chart, (*N* = 387).

Research Question 3

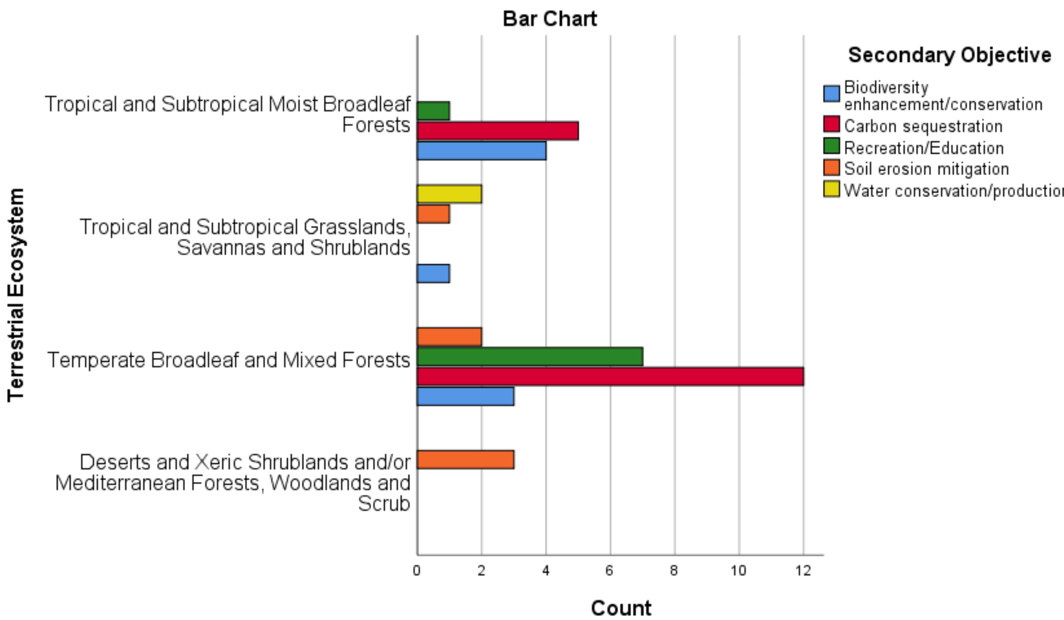

Figure 28. The secondary objective of tree planting projects compared against the terrestrial ecosystem that is situated at the project site, (*N* = 41).

Research Question 3.3

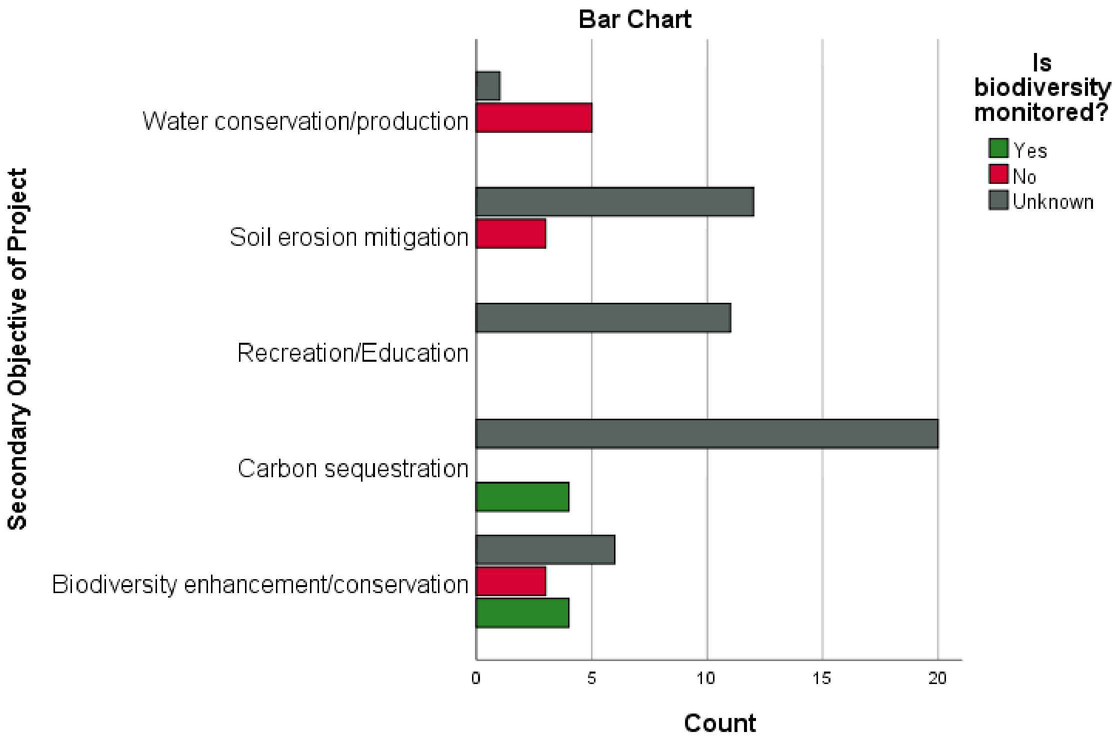

Figure 29. A bar chart comparing the difference between tree planting project sites that monitor for biodiversity and the secondary objective of the project, (*N* = 69). The count of the categories was too low for a statistical analysis to determine the association between the two variables.

Research Question 3.4

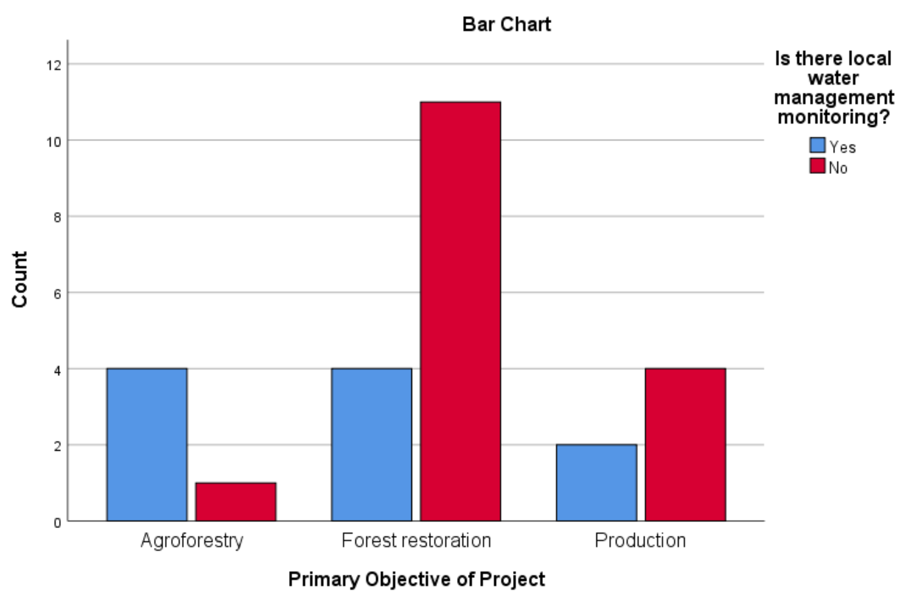

Figure 30. A bar chart comparing whether tree planting projects had implemented local water management monitoring in comparison to the primary objective of a tree planting project, (*N* = 26). The count of the categories was too low for a statistical analysis to determine the association between the two variables.

Appendix B

Example of an Interview Guide for a tree planting program

Can I record this interview and use your name in my report if I refer to this interview?

First please tell me about yourself and the work you do?

How many current projects and completed projects do you have for your tree planting program, where are they located?

What's the range of scale of your project sites (in terms of hectares)?

What is the typical tree density of your projects?

Do you have carbon credit projects, if so which ones?

Are any of your project sites certified, if so which ones and what certification?

Are all the projects for (biodiversity) conservation or restoration purposes or are they executed for other purposes such as economical - timber plantations, other ecological purposes?

What type of land cover are the projects implemented on (is it always on land that was previously forest?)

What are the typical types of forest are your projects helping reforest or afforest? For example dry, moisture tropical forests, floodplain forests etc.?

What is the previous land cover of your project sites?

If you plant on degraded land, what kind of ways is the land monitored to check for signs of degradation prior to tree planting e.g. forest cover?

How are projects and areas of land chosen or prioritized for projects of your program?

What kind of tree species are planted for your projects - hardwood, softwood?

Are the species you plant native? If so, how do you collect or decide which species' seeds are planted?

Do you plant exotic tree species, which types and if so which projects where? What is the main purpose for planting the exotic tree species?

Do you have measures for biodiversity conservation of your projects? If so, what type of measures do you have?

How frequently is biodiversity monitored for the projects, are there specific indicators that are focused on monitoring biodiversity (e.g. KPI of number of jaguar species)? Also is fauna and flora both monitored or just one or the other?

How much funding is spent on biodiversity measures and monitoring, and how much would you say this is as a percentage of the revenue?

Do you have measures for water management and monitoring, if so what?

Do you monitor the local water management of the project site(s), and if so how frequently?

Do you have a specific protocol that is followed for the setting up and implementation of each tree planting project site or is it site dependent?

In the future, where is it expected there will be further expansion of tree planting projects globally, is there a particular geographical biome or continental region that your tree planting program wishes to draw more focus towards?

Do you happen to have a list of species of trees that you use for projects that you would be happy to share? Or any other useful documents regarding this?

Do you have any further questions yourself?