Biophysical changes following landscape restoration

in Changting model restoration site in Fujian province, southern China

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MSc Thesis in Forest Management – Jägmästarprogrammet SY001
Advanced level (A2E), SLU course code EX0766, 30ECTS

Abstract

China has promised to tackle climate change by decreasing its emission and promote carbon sinks primarily by forest plantations and restorations. There is a growing debate about the impacts of large-scale restorations using few fast-growing species on the kind of ecosystem we are creating and its adaptation to the future environmental conditions. The aim of this thesis was to examine the recovery of both structural and functional attributes of ecosystem undergoing restoration using the Changting model restoration site as a case. Four sites were selected: a severely degrades site (DS), young mixed-species (YS) site where broadleaved species were planted on severely degraded land in 2008, old mixed-species (OS) with similar conditions and treatment as YS but planted in 1982 and secondary forest (SF) in Changting County, Fujian province, southeastern China. Trees and shrubs were inventoried in field and carbon stock was estimated with existing allometric equations. Understory vegetation and forest floor detritus were harvested and soil samples collected in the field for measuring carbon and nitrogen content using an elemental analyzer. General liner model analysis of variance (ANOVA) was preformed to determine significant differences between sites.

The results show drastic increasing in tree species richness and good recovery of carbon and nitrogen stock. A total of 43 species, representing 21 families, were recorded in all the study sites; of which 2 species were recorded in the DS, 15 species in OS, 16 species in YS and 29 species in the SF. The species diversity (Shannon index) was the least in DS (0.08) and highest in the SF (2.78) while the mixed-species sites had moderate diversity values (1.92 for YS and 1.76 for OS). The total carbon stock was the highest in the secondary forest (275.1 ± 159.0 tC ha^{-1}) followed by old (181.3 ± 31.0 tC ha^{-1}) and young (62.1 ± 23.6 tC ha^{-1}) mixed-species stands and the lowest being in the degraded site (13.7 ± 8.3 tC ha^{-1}).

The carbon stored in the woody biomass (both above- and below-ground) accounted for 67%, 60%, 10% and 8% of the total carbon storage in the SF, OS, YS and DS, respectively. The contributions of understory vegetation and forest floor detritus to the total carbon storage were 42% in the DS, 33% in the YS, 12% in OS and 9% SF. The total soil carbon stock decreased in the following order: SF (65 ± 12.3 tC ha^{-1}), OS (49.9 ± 21.3 tC ha^{-1}), YS (35.1 ± 21.1 tC ha^{-1}) and DS (6.6 ± 3 t C ha^{-1}). The rate of carbon accumulation was slightly higher in YS (6.1 ± 2.6 tC ha^{-1} yr^{-1}) than in OS (5.1 ± 1.1 tC ha^{-1} yr^{-1}). The rate of the carbon accumulation in the mixed-species stands is comparable (even more) to those of pure *Pinus massoniana* plantation but the former has a co-benefit of higher diversity than the monoculture. The soil nitrogen stock showed significant increase from degraded site to the other sites in the top soil. It can be concluded that the restoration projects in Changting are promising to successfully recover both structural (vegetation) and functional (nutrient cycling) attributes of the ecosystem while at the same time restoring some aspects of the biodiversity.

Keywords: Afforestation, Biomass carbon pools, Carbon and Nitrogen in soil, Broadleaves enrichment, Eroded red soil,

Sammanfattning

Den globala uppvärmningen och de associerade effekterna av klimatförändringarna är det största globala problemet idag. Stigande koldioxidkoncentration i atmosfären har länge bekräftats att orsaka den globala uppvärmningen. Kina som världens största källa av CO2-utsläpp har lovat i de nytecknade Parisavtalet att minska utsläppen och främja kolsänkor främst genom skogsplanteringar och restaureringar. Kina har en lång historia av restaurering av förstörda landskap för att minska riskerna för erosion, översvämningar och jordskred. Det finns en växande debatt om effekterna av storskaliga restaureringar av ett fåtal snabbväxande trädslag har på vilken typ av ekosystem vi skapar och dess anpassning till framtida miljöförhållanden. Syftet med detta arbete var att undersöka återhämtningen av både strukturella och funktionella egenskaper av ett restaurerat ekosystem med hjälp av Changting modell restaurerings plats som ett exemple. De metoder av restaurering som användes i Changting var uteslängning av ytterligare störningar från återhämtande sekundär skog (passiv restaurering och stödplanting på kraftig degraderad mark med blandade lövträd (huvudsakligen tre arter)

För detta examensarbete var fyra områden valde: ett kraftig degraderad bestånd (DS), ung blandskog bestånd (YS) som var planterat med lövträd på kraftigt degraderad mark år 2008, äldre blandskog bestånd (OS) som planterades 1982 med liknande metod och förutsättningar som (YS) och en sekundär skog (SF) i Changting County, Fujian provinsen, sydöstra Kina. Det fanns sex ytor i varje bestånd, förutom sekundära skogen (n=5) där träd och buskar inventerades och kollager uppskattades med allometriska ekvationer. Undervegetationen och förna skördades och jordprover togs på 0-20cm, 20-40cm och 40-60cm och mätes för kol och kväve i en elementaranalysator. Generell linjär modell variansanalys (ANOVA) användes för att bestämma signifikanta skillnader mellan bestånden.

Sammanlagt 43 arter, som representerar 21 familjer, hittades total i alla områden; varav 2 arter återfanns i DS, 15 arter i OS, 16 arter i YS och 29 arter i SF. Signifikant skillnad i stamtäthet upptäckes mellan bestånden ($p < 0.001$). Det unga och äldre blandbestånden var betydligt tätare än det degraderade beståndet och den sekundära skogen men ingen signifikant skillnad påvisades mellan YS och OS. Medan *Pinus massoniana* var det vanligaste trädslaget i all bestånden (63, 160 och 153 individer i DS, YS och OS respektive) *Liquidambar formosana* (76 individer) och *Symplocos confusa* (50 individer) var de vanligaste trädslagen i YS medans *Schima superba* (117 individer) och *Cunninghamia lanceolate* (101 individer) var de vanligaste trädslagen i OS, och *S. superba* (45 individer) och *Altingia gracilipes* i SF. Artmångfalden (Shannon index) var minst i DS (0.08) och störst i SF (2.78) medans blandskogs planteringarna hade måttliga mångfalds värden (1.92 för YS och 1.76 för OS). Höjd och diameter klass fördelningen visar att majoriteten av

individerna var av mindre storlek, vilket tyder på god föryngrings potential i de restaurerade skogarna.

Det totala kolförrådet var störst i den sekundära skogen (276.3 ± 159.0 tC ha^{-1}) följt av den äldre (181.4 ± 31.0 tC ha^{-1}) och yngre (62.1 ± 23.6 tC ha^{-1}) blandskogsbestånden och minst var det i den degraderade beståndet (13.7 ± 8.3 tC ha^{-1}). Det kol som lagrats i ved biomassa (både ovan- och underjord) stod för 67%, 60%, 10% och 8% av den totala kollagringen i SF, OS, YS and DS, respektive. Bidrag från undervegetation till den totala kollagringen var 17% i DS, 13% i YS och 2% i både OS och SF. Förna stod för 27% av det total kollagringen i DS, 20% i YS medans OS och SF lagrade 10% och 7% av den total kollagringen, respektive. Den totala markkollager minskade i följande ordning: SF (65 ± 12.3 tC ha^{-1}), OS (49.9 ± 21.3 tC ha^{-1}), YS (35.1 ± 21.1 tC ha^{-1}) och DS (6.6 ± 3 t C ha^{-1}). Det största lagret av kol hittades i topp 0-20 cm lagret i alla bestånden. Ackumuleringstakten för kol i biomassa av träd och annan vegetation var signifikant ($p = 0.023$) högre i OS än YS medans den tenderar att vara högre i jorden för YS (3.6 ± 2.5 tC ha^{-1} $år^{-1}$) än OS (1.3 ± 0.7). Kväve lagret på olika djup visade också betydande skillnader mellan bestånden; där den degraderade beståndet än de återställda omsådderna i jorddjupen 0-20 cm och 20-40cm.

Resultaten från detta examensarbete visar drastisk ökning i träd artrikedom och god återhämtning i kol och kväve lager. Graden av kol ackumulering i blandskogs bestånden är jämförbara (ännu mer) med dem av ren *P. massoniana* plantage men den förstnämnda har en till fördel, högre mångfald än monokulturer. Man kan dra slutsatsen att de restaureringsprojekt i Changting är lovande att framgångsrikt återhämta både strukturella (vegetation) och funktionella (närings cykling) attribut av ekosystemet medans samtidigt återställa vissa aspekter av den biologiska mångfalden.

Preface

This is a master thesis on advance level consisting of 30 hp and is the final work of my MSc in forest sciences, Jägmästare, given at SLU, The Swedish university of Agricultural Sciences. The work has been done for the Department of the Southern Swedish forest research Centre in Alnarp. I conducted a Minor Field Study in China with the support of Sida and the fieldwork was carried out in China during 2015 in collaboration with the Fujian Agriculture and Forestry University (福建农林大学).

Contents

1. Introduction

1.1 General background

Anthropogenic emissions of greenhouse gases are higher than ever before. The increase in emissions is mainly from economic growth, increasing population, use of fossil fuel and changes in land use. The connection between greenhouse gasses and global warming are now confirmed and annual average temperature has increased with 0.85 °C (IPPC, 2014). With the newly signed Paris agreement, the aims of the Kyoto protocol have enhanced. Overall, 175 counties have signed the agreement so far; agreeing on holding the increase in the global average temperature to well below 2 °C above pre-industrial levels (UNFCCC, 2015a).

During 2006 China took over the leading role as the world's largest national source of CO_2 emissions from the United states (Gregg *et al.*, 2008). The most up-to-date measurement states that China accounts for 20% of the global greenhouse gas emissions (UNFCCC, 2015b) The rate of increase in China is extraordinary, from 2000 to 2006 the CO_2 emissions increased with nearly 80% from fossil fuel combustion and cement manufacture (Gregg *et al.*, 2008). One part of the Paris agreement is the nationally determined contributions to the global response to climate change. China is now accelerating its previous climate actions to combating the global climate change. One of the important areas of actions is increasing carbon sinks, with the main goal that by 2030 increase the forest stock volume by around 4.5 billion cubic meters of the 2005 level. China plans to reach that goal by "vigorously enhance afforestation", restoring forest and grassland from farmland, conserving water and soil to mention the most important measures (Department of Climate Change, 2015). Already China's terrestrial ecosystems absorb a lot of carbon, 0.19-0.26 Pg C per year, which is comparable to that in geographic Europe. The northeast parts of China are a net source of carbon due to overharvesting and degradation of forest. While the southern part is the most important for China's total carbon sink and is accounts for more than 65%, which can by credited to regional climate change, large-scale plantation programs started in the 1980s and degraded ecosystems have started to recover (Piao *et al.*, 2009). Of the carbon sink in southern China the forest is the biggest contributor with 65% (Wang *et al.*, 2009).

The forest restoration programs conducted in China have had a strong focus on restoring one specific or a few specific ecosystem functions. In the late 1990, several ecological restoration programs have started due to major natural disasters. They were a direct response to the severe problems, such as flooding, dust storms and soil erosion, to name the most important, and the aim of the restoration was to battle this problems (Yin & Yin, 2010). Both the problems and restoration projects dates back much longer than the 90s, a high population pressures, economic growth and historical exploitation during the last decade have caused a lot of degradation in ecosystems (Yin *et al.*, 2005).

One of the biggest problems with the degradation is with eroded lands due to overexploitation and poor management. China haves 356 million hectare of eroded lands causing soil losses of more than 5 billion tons annually (Ministry of Water Resources in China, 2002 see Shi *et al.,* 2009 p. 323). The “red desert of Southern China” is the area that formerly was a densely forested hilly red soil region, a huge area of 218 million hectare and 10 provinces suffering degradation to the extent that it’s called desert (Zhao, 2002 see Xie *et al.,* 2012 p. 53). It’s not a new phenomenon; there have been severe problems for decades. And in the 1950s restoration efforts had been started in some of the worst degraded areas in China to address the problems, one of the worst area was Changting county in Fujian. To deal with the eroded lands planting of fast-growing tree species has been a favorable tactic in these areas. The restoration by planting can slowly increase vegetation coverage, followed by litter-fall mass, root networks and overall improvement of soil physiochemical properties – factors that decrease runoff and soil loss (Li & Shao, 2006).

1.2 Forest in climate change

Forest can be used to mitigate climate change and has been a focus of the climate change community in recent years (Davis *et al.*, 2003). There are mainly three strategies for forest to mitigate climate change: land use change (afforestation/reforestation), carbon management in existing forest and increasing use of wood material both for storing and as substitute for more fossil fuel based materials. Each strategy has its own risks and trade-offs and local conditions determines best suited alternative (McKinley *et al.*, 2011). Increasing the proportion of forest cover by afforestation/reforestation has been suggested to be an effective strategy to absorb atmospheric carbon dioxide and mitigate climate change (Peichl & Arain, 2006). As carbon storage in forest ecosystem is the largest of any other terrestrial ecosystems, its accumulated organic compounds has a long carbon residence time (Lorenz & Lal, 2010).

Forest restoration and regeneration promoted by humans will create novel ecosystem that differs from the original ecosystem in structure and species composition. It is mostly a combination of introducing new species, promoting a specific species or hampering other species Whether the actions are deliberate or inadvertent, humans have the potential to change ecosystem functioning (Hobbs *et al.*, 2006). However many ecosystem functions can be restored with forest restoration and several components of the original biodiversity can recover. The initial state of the degraded forest/ land together with the desired outcome, time frame and financial limitations are the main factors that influence restoration approach (Chazdon, 2008). When taking account of the initial stand, it is important to evaluate the spatial distribution, amount and quality of remaining vegetation, as these stand attributes determine the potential for natural regeneration (Chazdon, 2003). For severely degraded site where abiotic factors, such as soil removal, reclamation, by planting the most resilient species might be the only way to restore some biodiversity and ecosystem services (Prach *et al.*, 2007). With better initial stand in less degraded sites, reforestation with a larger variety of tree can be possible and can hasten recovery of species composition. Sites with just intermediate degradation, plantings or assisted natural regeneration can be incorporated along with natural regeneration to enhance the stand composition and structure, thereby speeding up the recovery of the degraded stand (Harvey *et al.*, 2008).

The popular form of forest restoration in tropical regions is large-scale plantation of only a few species. The effects of widespread plantations on future forest landscape and fauna are complex and poorly understood, decreased genetic diversity and increases biotic homogenization are factor that likely will have a large impact in the future (Chazdon, 2008). The use of monoculture tree plantations could also help establish invasive species and increase the vulnerability of the forest stand to species-specific pathogens (Hobbs *et al.*, 2006). With different restoration approaches, such as mixed-species planting, effects on recover of ecosystem services differ compared to monoculture, as it is recognized that there is a connection between biodiversity, functional traits and ecosystem services (Diaz *et al.*, 2004). Encouragements from politics by e.g. Paris agreement to increase carbon stocks in vegetation promotes forest restoration and conservations (Chazdon, 2008). With an aggressive program of restoration and changing forest practice over the next 50 years, it is estimated that 700 million hectares of forest could be restored and carbon sequestration of 60-87 Gt carbon could be achieved (Brown *et al.*, 2005). Fast-growing species planted in monoculture are preferred by many reforestation projects with the intention to quickly provide carbon offsets or just forest cover. The problems with fast-growing species are that they are short-lived and low-density. Long-term carbon sequestration is supported by the opposite, slow-growing, long lived and dense wood tree species. The slow-growing increase in abundance and biomass throughout the stand development, and they also generally have a slow turnover of woody tissues, thus binding the carbon in the ecosystem for a long time (Diaz *et al.*, 2004).

1.3 Forest restoration: Concepts and Approaches

The Society for Ecological Restoration (SER, 2004), defines ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed”. Ecological restoration is an activity that initiates or improves recovery of an ecosystem’s health, sustainability and integrity. As consequences of human activity ecosystems that have been destroyed, degraded or transformed directly or indirectly are now subjected to be restored (Rodrigues *et al.*, 2009; SER, 2004).

There are three basic concepts of restoration: reclamation, rehabilitation and restoration. Reclamation generally involves site improvement to allow vegetation to establish and colonize the site. It may be the only option for increasing the utility or economic value of sites where abiotic factors such as soil removal or toxic substrata hinder establishment. Rehabilitation involves actions that repair damaged ecosystem services such as productivity or soil fertility. The target is usually native ecosystem structure and function; however exotic species are frequently included. Restoration includes actions to restore degraded ecosystem with the target of their presumed historic conditions (Sovu, 2011; Chazdon, 2008). There is, however, on-going debate whether the goal of restoration should be to recovery the past ecosystem or a novel ecosystem that will adapt to the changing environmental conditions in the future.

Taken into account the extent of land degradation, the spatial distribution, abundance and quality of remaining vegetation, there are different approaches for restoring degraded ecosystems (Chazdon, 2008). The approaches can be divided into passive or active restoration or a combination of both. Passive restoration is using natural recovery by eliminate or reduce disturbances (e.g. grazing, fire and destructive logging) that causes ecosystem degradation. Active restoration entails direct human intervention where it is necessary to influence the successional trajectory (e.g. reintroduce regionally extinct species) or accelerate the recovery. Methods of active restoration include, planting, prescribed burning, invasive species control and more (Dellasala *et al.*, 2003).

1.4 Restoration in Changting

Changting County, located in western Fujian Province in Southeast China, was historically covered by luxuriant vegetation with light soil erosion. However, as it was one of the most poverty-stricken counties of China, its forests have suffered enormously from anthropogenic disturbances. Its poor economic performance is primarily due to poor infrastructure, the lack of natural resources and mountainous landscape not suitable for farming, about 68% less arable land per capita than China’s 0.1 ha arable land per capita (Wang *et al.*, 2012; Zhang, 2011). Before 1990s fuelwood collection was made from harvesting trees and shrubs, which is a vital share of farmers’ livelihoods besides agriculture. A rapidly increasing rural population over the last half-century led to an unsustainable intense disturbance on the ecosystem. The exploitation of the hilly forest ecosystem in Changting County exceeded the degradation threshold; resulting in severe forest degradation and soil erosion (Wang *et al.*, 2011).

The county’s government has made great efforts in soil and water conservation since 1950s, such as artificial afforestation and closing access to hillsides for promoting natural regeneration. The long ongoing struggle with degradation problems has received a lot of attention, and numerous restoration projects and studies have been done in the County. *Pinus massoniana* Lamb. is the most widely used timber forest species and protection forest species in the area and accounts for more the 40% of the forest area (Zhou 2001 see Li, 2015 p.20). Due to its strong adaptability, easy propagation and rapid growth have been favored in afforestation in soil erosion areas (Hunag 2009 see Li, 2015 p.20). The earliest restoration initiatives were unfortunately destroyed when the properties rights of forest and agriculture land was reformed and the local farmers received responsibilities of the land. They cleared most of the forest and reclaimed slopes for agriculture to earn a livelihood (Wang *et al.*, 2011). Combine with some special physiology features of *Pinus massoniana* making most of the woodlands unable to play an efficient role in soil conservation. The *Pinus massoniana* inhibiting the growth of other plants by root secreted acid substances (Zhang and Wang 2010 see Li, 2015 p.21) The woodlands become single structure with little near surface vegetation and low biodiversity a phenomenon called the “ Floating Green” which means from far distance the hill looks green but from close distance the soil erosion become visible (Liang et al. 2008 see Li, 2015 p.20). During this reform from 1985 to 1995, both vegetation and forest covers decreased, and areas exposed to severe soil erosion increased with 100.9% (Cao *et al.*, 2009). In 2000 “Soil erosion comprehensive treatment program of Changting County” including both environmental conservation and poverty reduction started. Treating the severe soil erosion with active restoration projects and passive restoration projects compensating farmers for their loss of economic activities, such as fuelwood collection and slope-land cultivation, have been adopted (Lu 2002 see Wang *et al.*, 2011 p. 81). Depending on extents of ecosystem degradation several different active restoration approaches have been used in degraded *Pinus massoniana* stand; ground vegetation restoration with horizontal ditch tillage, base fertilizer and sowing grass seeds of *Digitaria sanguinalis, Setaria glauca, Paspalum orbiculare, Magnolia multiflora* (Zeng 2003 see Li, 2015 p.23); planting drought-barren resisted grasses to promote plant growth (Li, 2015); broadleaves enrichment planting of suitable species (e.g. *Lespedeza bicolor*, *Quercus fabri* and *Paspalum notatum*) combined with sowing of grass and shrubs and if necessary soil and water conservation engineering measures (Guo et al. 1998Li, 2015 see p.24).

Monitoring of vegetation recovery from 1984 to 2009 showed that the loss of soil is irreversible when the vegetation cover is below 20%, which is assumed to be a degradation threshold that leads to sustained degeneration of vegetation community, erosion and declining soil fertility (Gao *et al.*, 2011). Following restoration measures, however, the total soil erosion has decreased by 68% from 1999 to 2007, and areas suffered from erosion have decreased by 45%. In the same time, the vegetation cover has increased by 15% in all of Changting County; and in the one specific project area by 79% (Cao *et al.*, 2009). Species diversity of trees, shrubs and herbs has also increased with restoration success. The number of species found in the most degraded sites are only seven but sites planted with conifers have 15 species (Shanshan, 2015). The potential for carbon storage in forest vegetation of Fujian Province have been estimated, and the carbon storage in forest vegetation has increased by 96.7 Tg C from 1978 to 2008 with an annual increase of 4.8 Tg C. Carbon storage, however, varied with species, age and ownership. The carbon storage in the biomass tended to be higher in mature broadleaved and state-owned forest. More detailed carbon studies have been done in Changting County; examining the accumulation of carbon in both vegetation and soils after planting *Pinus massoniana* on bare land in 1981. Since establishment until 2005, the total carbon storage in this plantation has increased to 130 Mg C ha^{-1}, 10 times higher than the control, most of it in aboveground biomass 92 Mg C ha^{-1}. The accumulation rates of ecosystem carbon were 4.88 Mg C ha^{-1} yr^{-1} (Xie *et al.*, 2012).

There is still a gap in the research in our understanding of recovery of structural and functional components of restored ecosystems, as the previous studies have mostly focused on either functional recovery or structural recovery after restoration. Functional recovery, such as erosion and carbon sequestration, have had a great importance in the area and been the focus of many research. The structural recovery of the ecosystem is also equally important as it relates to biodiversity and overall structure of the forest. With wide recognition of the links between functional traits, biodiversity and ecosystem services (Diaz *et al.*, 2004), it is important to investigate the links between structural or functional recovery to fully examine the success of restoration endeavors.

2. Objective

The main objective of this study was to examine the recovery of structural and functional attributes of a restored ecosystem in the Changting model restoration site in Fujian province. By comparing degraded and restored ecosystems, both the structural and functional recoveries were evaluated. Specifically, the study presented in this thesis investigated (1) the species composition and diversity changes, (2) total carbon and its different pools, (3) total nitrogen stocks as indicator of soil fertility at two development stages following restoration compared with degraded land and secondary forest.

The specific research questions and the corresponding hypotheses of the study were:

(1) How do the stand structure and diversity recover following restoration planting?

Hypothesis: Clear changes will be seen already at an early stage of recovery.

(2) How do the carbon stock and its different pools recover following restoration planting?

Hypothesis: Carbon stock significantly increases shortly after restoration compared to the degraded sites and vegetation has the biggest impact on carbon pool at both young and old mixed-species stands

(3) Does restoration measure influence the total nitrogen content in the soil?

Hypothesis: The total nitrogen stock in the soil increases dramatically in restored site than degraded.

3. Materials and Methods

3.1 Study area and site description

The study was carried out in Changting County located in western Fujian Province in Southeast China (25°18´40´´ - 26°02´05´´N, 116°00´45´´ - 116°39´20´´E; Figure 1). The area is dominated by low hills and uplands; characterized by a humid, subtropical monsoon climate with high mean precipitation (1730.4 mm $year^{-1}$) and warm annual temperature with a mean of 18.3 °C and a minimum temperature of 7.9 °C (Yang *et al.*, 2005 see; Wang *et al.*, 2011 p. 80). The dominant soil type in the area is granite red soils. Previously the area was covered by luxuriant vegetation with light soil erosion (Chen, 1998 see; Wang *et al.*, 2011 p. 80).

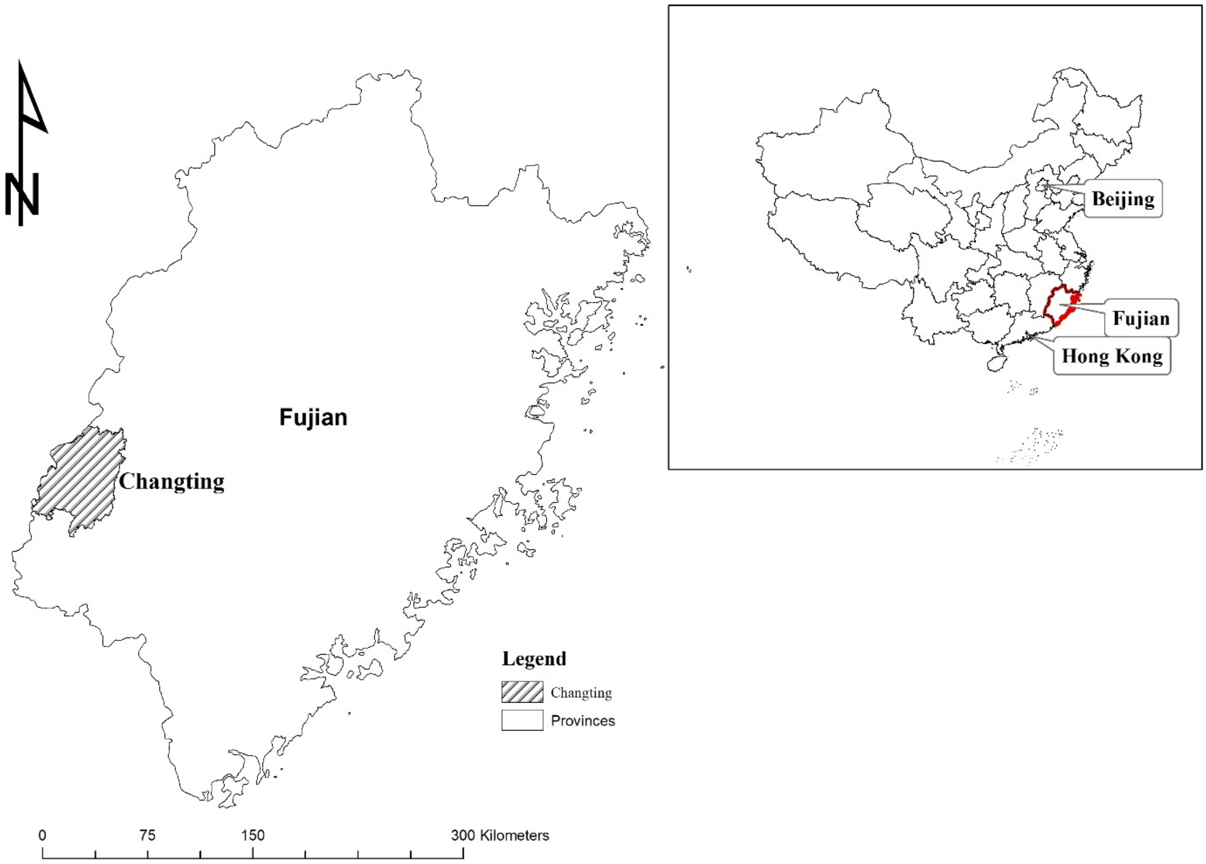

Figure 1. Map of China (right) with Fujian province marked and two reference cites. The location of Changting in Fujian province is marked to the left.

In cooperation with the local soil and water conservation office at Hentai city (a city in central Changting County), four sites were selected to represent the development of one restoration technique used in the area (Figure 2). The different sites selected for this study were degraded site, young mixed-species, old mixed-species and secondary forest.

The degraded site is a severely degraded site with little to no vegetation. It was completely bare land until 2002 when it was protected from further human disturbance by a policy called forest conservation. There is some natural regeneration with insignificant amount of *Pinus massoniana* and some bushes and grasses. This site served as a control in the thesis as it's the closes to the historical bare land of the area. The exclusion from cuttings by the policy has so far done little for restoring ecosystem services on the site.

The young mixed-species stand was in similar condition as the degraded site until 2008 when a restoration project started. The project broadleaves enrichment planting involved planting of, *Elaeocarpus sylvestris* (Lour.), *Liquidambar formosana* (Hance) and bushes *Lespedeza bicolor* (Trucz.) in a naturally regenerated *Pinus massoniana* stand, comparable to the degraded site. The trees and shrubs were planted in holes, measuring 50 x 40 x 30 cm with a spacing of 2.3 x 2.3 m and some herbs were sown alongside tree planting around the planting hole. The herbs were expected to help establish trees in such a degraded site.

The old mixed-species stand received similar treatment as the young broadleaved site in 1982. Enrichment planting of broadleaved tree species was done in a poorly naturally regenerated site. There is no documentation available on exactly what and how many was planted. Today it is dominated by *Pinus massoniana*, followed by *Schima superba* (Gardn. & Champ.) and *Eurya loquaiana* (Dunn) as the dominant species that most likely was planted in the 1980s. Later Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) has also been planted under the existing trees. The stand is mostly dense with a few openings, full of regeneration.

The secondary forest is a rather small area that differs a lot from the surroundings as it is old natural forest. It has been mostly spared from cuttings due to the fact that the area is considered sacred, so called "feng-shui" woodland and should not be used for cuttings or farmland. There is no documented history of the stand however here the stand structure suggests that there has been some disturbance, probably cuttings, around 100 years ago that led to regeneration of pine in the area. The stand today is dominated by *Altingia gracilipes* Hemsl. followed by *Pinus massoniana* when considering volume.

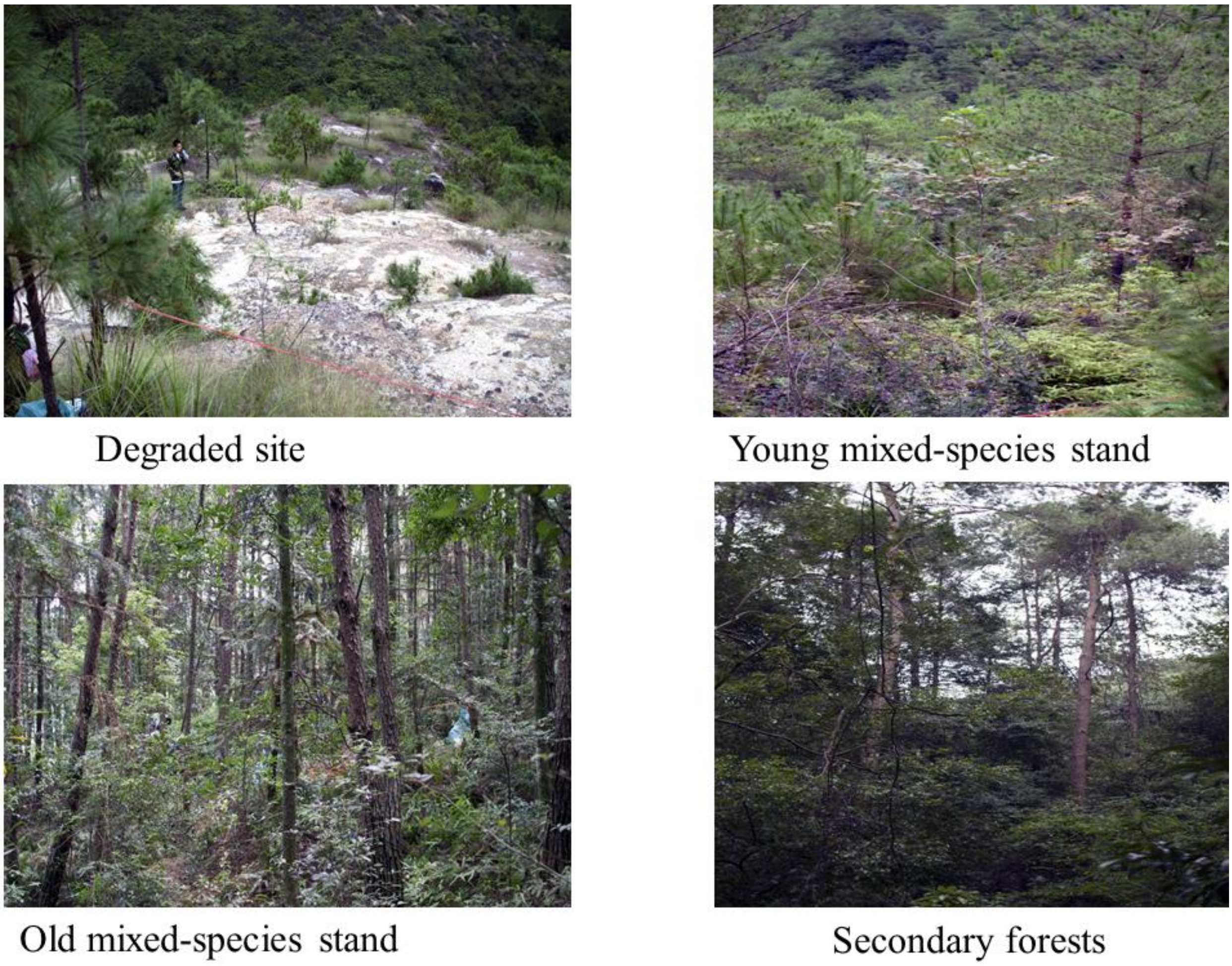

Figure 2. Overview of the different sites selected for the study.

3.2 Inventory and sampling

Inventory and sampling was conducted during September – October 2015. In each site, six plots were laid out except in the secondary forest where only five plots could be fitted inside the area. Where possible the plots were laid out in a pattern with two rows along the slope with three plots each, the distance between the plots and the rows was determine by the area of the site so there would be a good distribution. However the terrain made it difficult to always keep even distance. Each plot was 15 x 15 m. All trees with higher than 1.3 m and with a diameter above 1 cm was included. The diameter at breast height, tree height and species was recorded.

Understory vegetation was harvested and forest floor detritus was collected separately in five 1 x 1 m subplots in each 15 x 15 m plot. Subplots was put out in a × pattern, one in each corner and one in the middle, with 2 m buffer to the edge. All samples were weighed in the field for fresh weight and then oven dried at 80 °C until completely dried before dry weight determination.

Five soil pits was dug next to the subplots in each plot. Soil samples were collected from the following depth interval: 0-20, 20-40 and 40-60 cm. For each depth, one composite soil sample, consisting of a mix from all five soil pits in each plot, was collected for analyzing carbon and nitrogen stocks,. Soil bulk density was determined for each pit and depth by the core method. A cylindrical metal bucket was hammered into the soil at a specific depth, and the soil core was then oven dried until stable weight.

3.3 Carbon and nitrogen analyses

Prior to analysis, the soil samples were air-dried, grounded and sieved through a 250-μm sieve while the forest floor detritus and understory vegetation samples were oven dried, milled to fine powder and sieved through a 1 mm sieve. The total nitrogen and carbon content was determined using elemental analyzer (Vario Max, Elementar Analysensysteme, Hanau, Germany). It uses catalytic tube combustion of the samples and separating foreign gases with desired before a thermal conductivity detector, which registers the amount of carbon and nitrogen. About 0.25g of each vegetation and forest detritus sample and about 1g of each soil sample was used for the analysis.

3.4 Calculation

Stand development

To evaluate the stand development after restoration, four parameters were calculated from the inventory data.
Biodiversity in the tree layer with two indexes, Species richness with the Menhinick index

$$D = \frac{S}{\sqrt{N}}$$

where S is the number of detected taxa and N is the total number of organisms.
Species diversity with the Shannon index

$$H = \sum_{i=1}^{S} p_i \, |ln\, p_i|$$

where p_i is the relative abundance of the taxa i and S is the number of detected taxa (Magurran, 1996).

Height and diameter class distributions were calculated from all the plots then converted to stems per hectare and divided in 10 cm classes.

Stand density was calculated per plot before statistical analyses were preformed.

Soil

The bulk density was calculated as the oven-dry mass of the sample divided by the sample volume according to (Blake & Hartge, 1986) as follows

$$BD = \frac{ODW - CW}{CV}$$

where: *BD* = Bulk density %, *ODW* = Oven-dry weight g, *CW* = core weight g and *CV* = core volume cm^3.

The carbon and nitrogen stock in the soil is calculated with the following equation (Batjes, 1996)

$$Stock = BD \times D \times C \times 100$$

where *BD* is bulk density g/cm^3, D is the thickness of the layer cm and *C* is the concentration % measured using element analyzer; and then converted to tones per hectare.

Tree and shrub above ground carbon

Trees and shrubs biomass was calculated using species specific allometric functions or general allometric functions when no specific one was found. A list of functions used and some important parameters gathered from previous research can be viewed in Table 1. Above ground biomass (AGB) is calculated for each individual tree/ shrub (*i*) in each plot (*j*). After calculating the biomass, the carbon stock was computed by multiplying AGB with 0.47 (IPCC, 2006). Above ground carbon (*AGC*) for tree and shrub was calculated as follow

$$AGC = \sum_{i=1}^{T} AGB_i \times 0.47$$

Tree and shrub below ground carbon

The below ground carbon (*BGC*) for root biomass from trees and shrubs was calculated by using the data on *AGC* and multiple it with the root to shoot ratio (Ravindranath, 2008). According to Cairns *et al.* (1997), the mean ratio for this forest domain is 0.26.

$$BGC = AGC * 0.26$$

Carbon content of understory vegetation and forest floor detritus

From the inventory where fresh and dry weight measured, percentage total nitrogen and total carbon was calculated for each subplot (1x1m) before calculating the average per site. The concentration of carbon and nitrogen was calculate as dry weight and then converted into tons per hectare.

Ecosystem carbon accumulation rate

The degraded site was considered as a reference for the young and old mixed-species stands before restoration efforts was made. The annual ecosystem (biomass plus soil) carbon accumulation was calculated as the difference between the amount of carbon in the degraded site and the young and old mixed-species sites divide be the time since restoration with 8 and 33 years, respectively.

Deadwoods

In general, deadwoods were scarce in the area as most of them were collected for firewood, but there were some standing and lying deadwoods in the secondary forest, young and old mixed-species stands. The lying deadwoods, mainly small branches, were included in the forest floor detritus inventory. Standing deadwood was calculated as living tree if it was recently dead and intact as most was. The volume of standing broken deadwood was calculated using $= \pi r^2 h$ and multiple with a taper factor suited for each tree.

Table 1 Allometric equation for biomass of trees and shrubs with reference and the most important parameters for each equations.

Species	Equation	Source	R2	n	H (m)	D (cm)
Castanopsis fargesii	AGB $W_A = 0.0307(D^2H)^{1.0216}$	(Zuo *et al.*, 2015)	0,98	21	6,3-19,5	5,2-35,5
Cunninghamia lanceolata	AGB = 115,84 $(D^2H)^{0,75}$	(Zhang *et al.*, 2007)	0,94	47	Young to	mature stand
Liquidambar formosana	AGB = 34,51 $(D^2H)^1$	(Zhang *et al.*, 2007)	0,95	10	Young to	mature stand
Pinus massoniana	TotalB=0,1377(D2H)0,8172	(Wu *et al.*, 1999)	0,99	120	4,1-19,1	4,8-23,2
Schima superba	Ln(AGBp) = –3.74 + 2.79×Ln(H)	(Arshad *et al.*, 2015)	0,84	6	1,9-4,6	1,5-4,2
Schima superba	AGB = 71,03 $(D^2H)^{0,91}$	(Zhang *et al.*, 2007)	0,96	17	Young to	mature stand
Mixed species	AGB $W_A = 0.0632(D^2H)^{0.9185}$	(Zuo *et al.*, 2015)	0,92	140	5,2-35,5	2,9-21,3
Mixed species for small tree and shrubs	Ln(AGBp) = –3.23 + 2.17×Ln(D)	(Arshad *et al.*, 2015)	0,71	96	0,5-4,6	0,4-4,9

Lianas

There was a small amount of lianas in the secondary forest that were excluded from the carbon stock calculations as they are difficult to measure because of the length, they can cross several plots and there is a lack of biomass equation. Since they are not a significant component of this ecosystem, should they not be measured (Pearson *et al.*, 2005).

3.5 Statistical analysis

Analysis of variance (ANOVA) was used for the statistical evaluation of differences in mean values between different restoration sites. Statistical analysis of the data was performed using Minitab16 software by using the function general linear model with Turkey's test. Significant differences were reported when p-value was less than 0.05. Tree above- and below-ground carbon content were logarithmic transformed and weighted against the number of stems before the ANOVA GLM analysis to satisfy the normal distribution assumption for ANOVA.

4. Result

4.1 Species composition and diversity

A total of 43 species, representing 21 families, were recorded in all the study sites; of which 2 species were recorded in the degraded sites, 15 species in old mixed-species stand, 16 species in young mixed species stand and 29 species in the secondary forests (see Appendix). *Pinus massoniana* was the most abundant species in the degraded site (63 individuals), in the young mixed-species stand (160 individuals) and old mixed-species stand (151 individuals). In addition, *Liquidambar formosana* (76 individuals) and *Symplocos confusa* (50 individuals) were the most abundant species in the young mixed-species stand while *Schima superba* (117 individuals) and *Cunninghamia lanceolate* (101 individuals) were the most abundant species in the old mixed-species stand. The relatively abundant species in the secondary forests were *S. superba* (45 individuals) and *Altingia gracilipes* (28 individuals).

The diversity of the tree and shrub layers was characterized by two indices, Menhinick's index of species richness and Shannon's diversity index. The difference between the indexes is that the Shannon index takes into account both the numbers of species present and the dominance or evenness of the species in relation to one another while the Menhinick's index only takes into account the number of species found. Both indices showed an increasing pattern as follows: secondary forest > young mixed-species stand > old mixed-species > degraded site (Figure 3). The secondary forest had the highest values for both species richness and evenness while the young and old mixed-species stands had higher diversity (evenness) than species richness. In the degraded site, diversity is lower than richness due to the fact that only one species was dominant in this site (Figure 3).

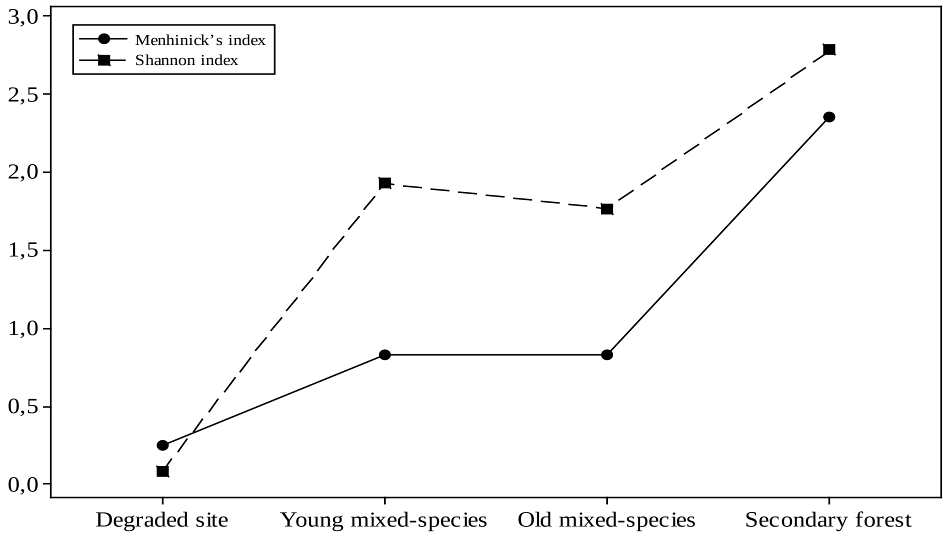

Figure 3 Species richness Menhinick's index and species diversity Shannon index for the four sites

4.2 Stand Structure

Stem density for tree and shrub larger than 1.3 m and diameter above 1 cm is presented in Figure 4. GLM ANOVA showed significant difference among the sites ($p < 0.001$). The Degraded site had the lowest number of stems (mean = 444.4 stems ha^{-1}). The young and old mixed-species stands were significantly denser then degraded and secondary forest (1688.9 stem ha^{-1}) but no difference between them; the mean stem density (3155.6 and 3266.7 stems ha^{-1}) for young and old mixed-species stand, respectively (Figure 4).

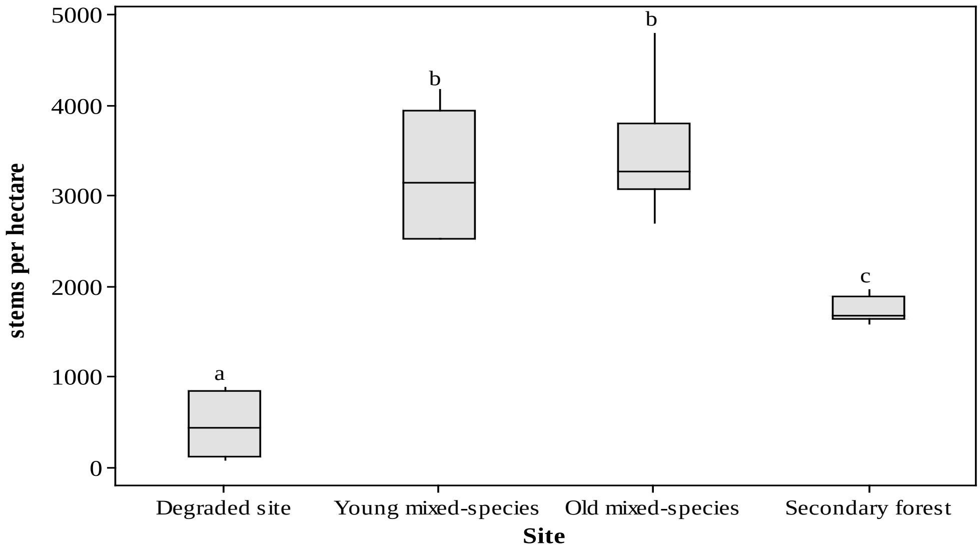

Figure 4 Stem density in stems per hectare for the four sites with grouping, there is a significant difference between the means if they have different letters (p<0.001)

The height class distribution varied greatly among sites, most stems were the smallest classes (Figure 5) irrespective of the site. The old mixed-species stand had a considerable proportion of its stems in the middle classes than the other sites. The degraded site had no stems taller than 5 m and the young mixed-species stand had trees not more than 10 m tall. The secondary forest had the majority of stems below 10 m in height and 9 to 45 stems per hectare from 10- 37 m (Figure 5).

The diameter class distribution also showed a similar "inverted j" curve as height class (Figure 6). The secondary forest had trees as big as 95.8 cm at breast height including 10 more trees larger than 47 cm. The young and old mixed-species stand had a similar diameter class distribution as the secondary forest, with a majority in the smallest class. The degraded site differed from the restored sites by having less in the smallest diameter range than the immediate larger trees, indicating poor regeneration.

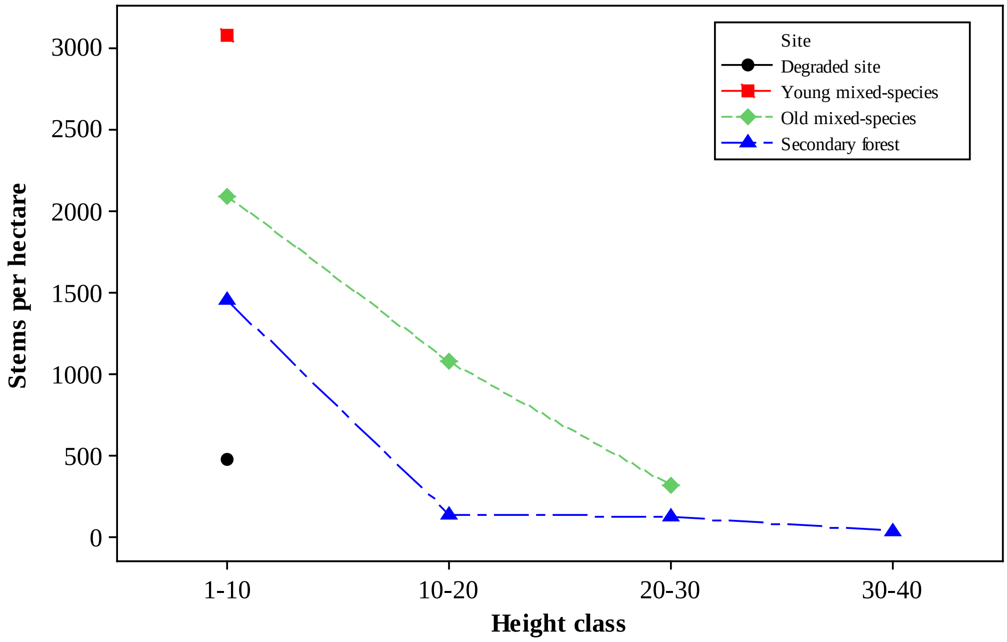

Figure 5 Height class distribution for the four sites divided in ten centimeters classes

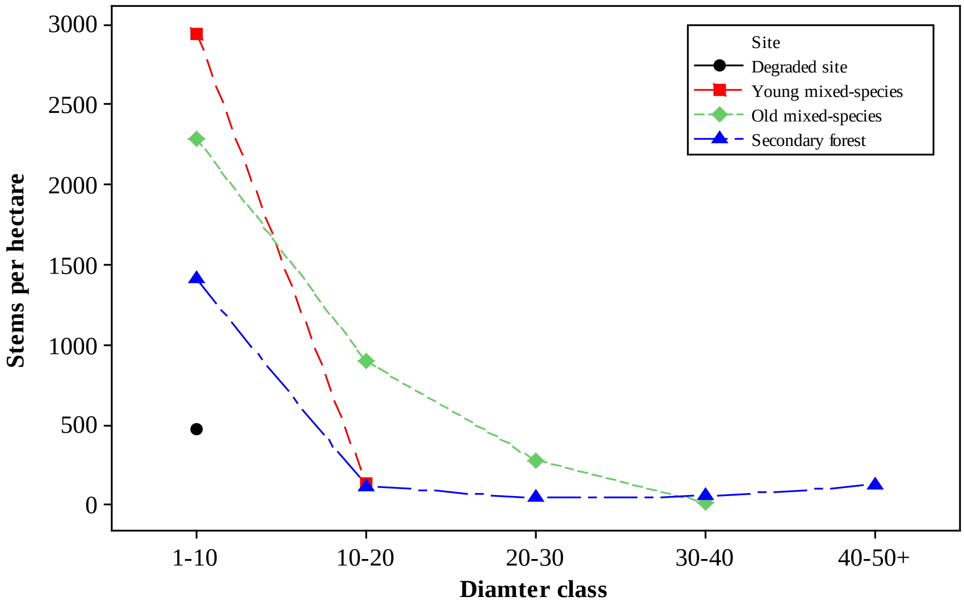

Figure 6 Diameter class distribution for the four sites divided in two centimeters classes and reported in stems per hectare

4.3 Carbon stock

GLM ANOVA revealed significant differences in total carbon stock and carbon stock of different pools ($p < 0.001$) except deadwood among sites. The total carbon stock was the highest in the secondary forest followed by old and young mixed-species stands and the lowest being in the degraded site (Figure 7). The carbon stored in above ground biomass of trees accounted for the largest part of the carbon storage in the old mixed-species stand and secondary forest, representing 48% and 53% of the total carbon storage, respectively. Including the carbon stock in below ground tree biomass, the carbon storage in old mixed-species stand accounted for 60% of the total carbon storage while the secondary forests stored 67% of the total carbon stock in the biomass. For the degraded site and young mixed-species stand, the woody biomass stored 8% and 10% of the total carbon store, respectively (Figure 7). Deadwoods had a small share of the carbon pool and too few recordings were made for doing any statistic comparison. Largest amount of carbon in deadwood was found in secondary forest 3.8 t C ha^{-1} while insignificant amount in young and old broadleaves and no deadwood in the degraded site (Figure 7). Comparison of means for each carbon pool can be found in appendix II.

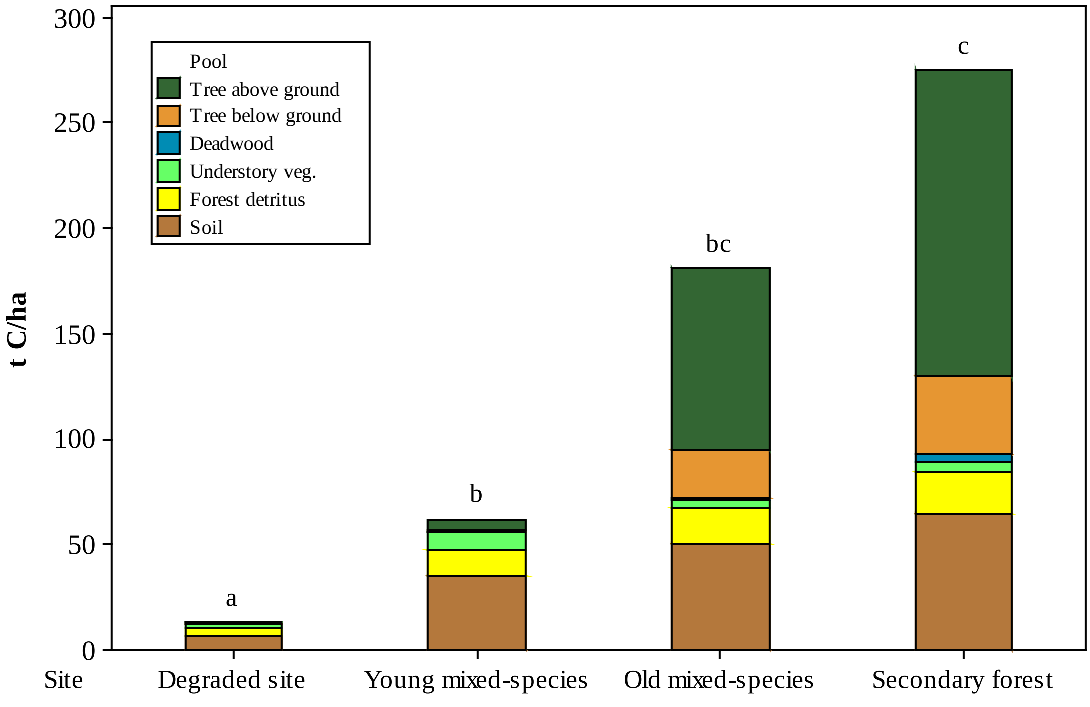

Figure 7 Carbon storage for the different pools of the ecosystem presented in tons carbon per hectare. Significant difference in total carbon stock (sum of carbon stock of different pools) is shown on bars with different letter ($p < 0.05$)

The carbon stock in the forest floor detritus increased rapidly and significantly ($p < 0.01$) from the degraded site (3.7 ± 3.2 tC ha^{-1}) to the young broadleaves (12.6 ± 2.5 tC ha^{-1}) which in turn was significant lower than that in the secondary forests (Figure 7). Overall, the forest floor detritus accounted for 27% of the total carbon stock in the degraded site, 20% in the young mixed-species stand while the old mixed-species stand and the secondary forest stored 10% and 7% of the total carbon stock, respectively

The carbon stock in the understory vegetation was significantly ($p < 0.01$) higher in the young mixed-species stand than the other sites. The contributions understory vegetation to the total carbon storage was 17% in the degraded site, 13% in the young mixed-species stand and 2% in both old mixed-species stand and secondary forest.

The total soil carbon stock varied significantly ($p < 0.001$) among sites; the highest being in the secondary forest (65 ± 12.3 tC ha^{-1}) and the lowest being in the degraded site (6.6 ± 3 tC ha^{-1}). The total soil carbon stock didn't differ between the young (35.1 ± 21.1 tC ha^{-1}) and old (49.9 ± 21.3 tC ha^{-1}) mixed-species stands. The largest stock of carbon was found in the top 0-20 cm layer in all the sites, but there was a decreasing tendency of soil carbon stock in the subsequent soil depth interval, particularly the decrease was marked in the secondary forest (Figure 8).

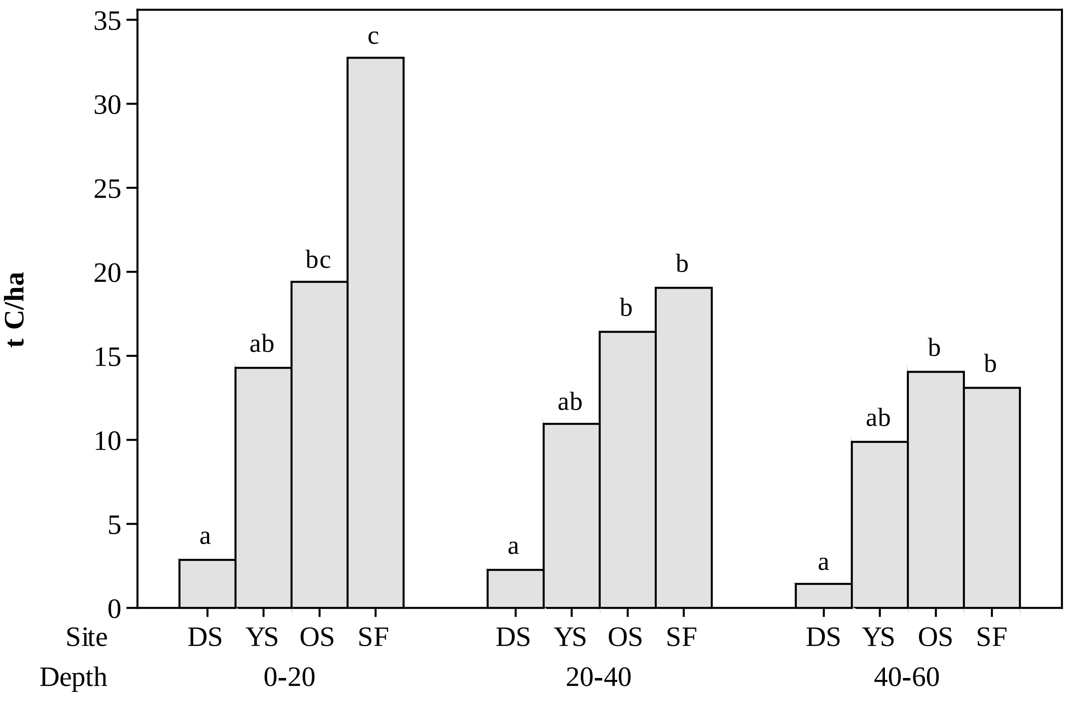

Figure 8 Soil carbon for the four site DS (Degraded site), YS (Young mixed-species), OS (Old mixed-species) and SF (Secondary forest) at three depths intervals in t C ha^{-1}. Different letters within the same column shows significant difference ($p<0.001$).

4.4 Carbon accumulation rate

The mean annual ecosystem carbon accumulation rate didn't differ between young and old mixed-species stands (Figure 9) although it tended to be more in the young stand (6.1 ± 2.6 tC ha^{-1} $year^{-1}$ versus 5.1 ± 1.1 tC ha^{-1} $year^{-1}$). However, the rate of carbon accumulation in biomass of trees and other vegetation was significantly (*p* = 0.023) higher in the old than young mixed-species stand while it tended to be higher in the soils of the young (3.6 ± 2.5 tC ha^{-1} $year^{-1}$) than the old mixed-species stand (1.3 ± 0.7).

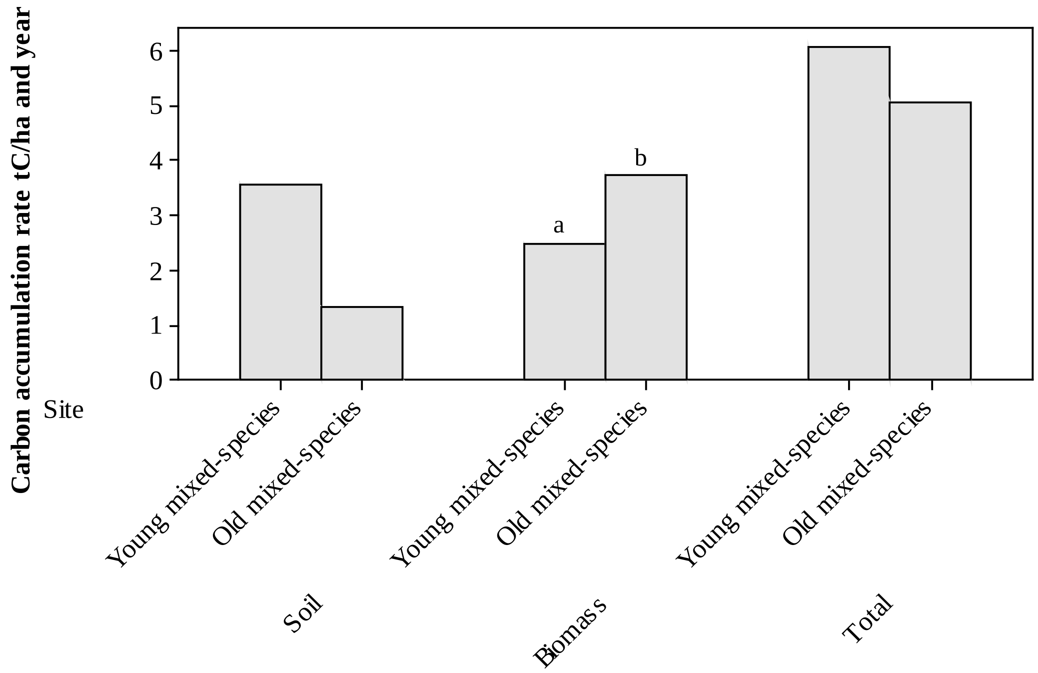

Figure 9 Carbon accumulation rate for young mixed-species and old mixed-species in tons of carbon per hectare and year divided in two different carbon pools, Soil and Biomass, and Total. Bars with letters show significant difference between each other (p< 00.5 the rest is not significant different.

4.5 Nitrogen stock

The total nitrogen stock was significantly (p = 0.001) higher in the secondary forests (7.1 tN ha^{-1}) than in the degraded site and young mixed-species (Figure 10). There was no significant difference in total nitrogen stock between degraded and young mixed-species stand and between old mixed-species stand and secondary forests. The nitrogen stock at different soil depths also showed significant differences among the sites; where the degraded site had lower nitrogen content than the restored sites in the first two depth intervals, 0-20 cm and 20-40 cm. In the 40-60 cm soil depth, the nitrogen stock was significantly higher in the old mixed-species stand than in the degraded site, which in turn had statistically similar nitrogen stock as the young mixed-species stand and the secondary forests.

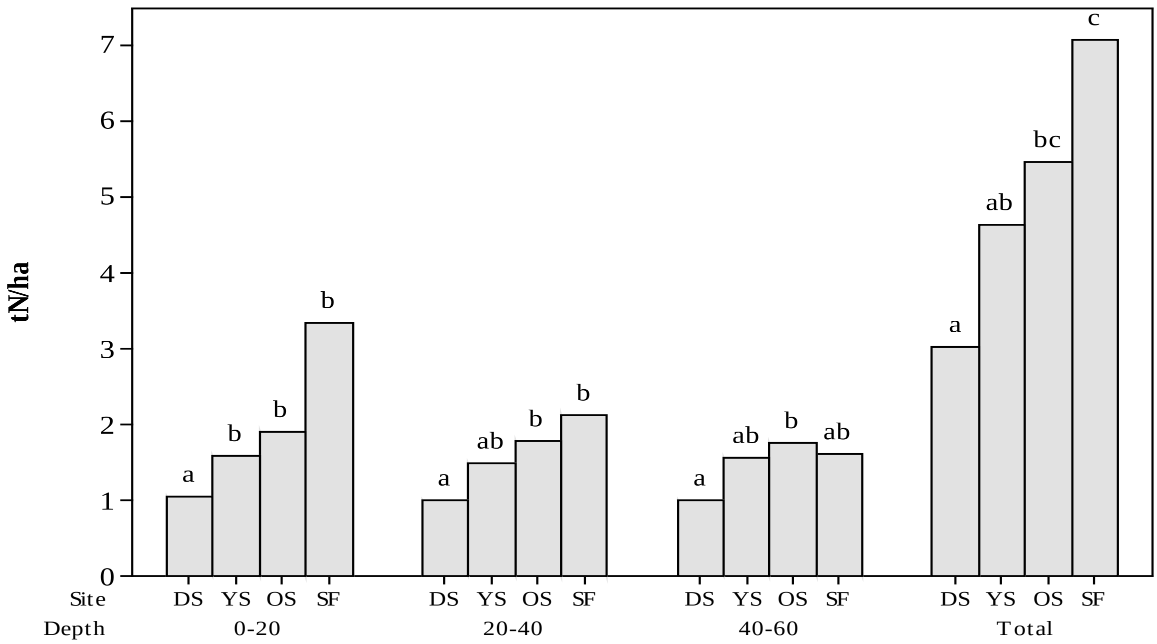

Figure 10 Soil nitrogen for the three depths intervals (cm) and the total divided for the site DS (Degraded site), YS (Young mixed-species), OS (Old mixed-species) and SF (Secondary forest). Letters within a depth interval shows significant difference (p>0.05).

4.6 C:N ratio

The C:N ratio showed significant difference (p < 0.001 for all three soil depth intervals) between degraded site and the restored sites. In all the sites, there was a decreasing tendency of C:N ratio with increasing soil depth (Figure 11).

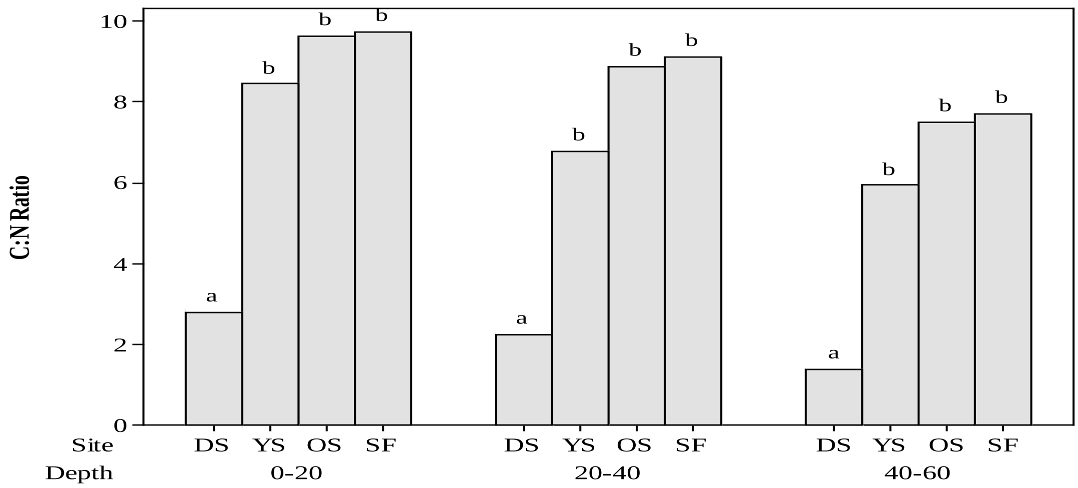

Figure 11 C:N ratio for DS (Degraded site), YS (Young mixed-species), OS (Old mixed-species) and SF (Secondary forest) over the three depths intervals. Bars with different letters within a depth interval shows significant difference ($p < 0.05$)

5. Discussion

5.1 Stand structure

After restoration has been started, it did not take long to see a dramatic change in stand structure. Already after 8 year, the young stand remarkably differs from the degraded site in many ways and the differences continue to increase over time as seen in the structural recovery in the old stand. The stem density, diameter and height class distributions provide more insights considered together then alone. In young stand, there are many small trees and few larger ones; it's a quiet even stand with slight difference due to slope. In the old stand, the tree layer is dominant with ample regeneration both underneath and in openings. The tree and shrub diversity in the young and old mixed-species stands are comparably high, even though *P. massoniana* is dominating. Previous studies in the same area as this study examining the transition from bare land to mixed broadleaves found only three tree species in a conifer stand, which are far less than species recorded in both young and old mixed-species stands in the present study. But the results in the study similar with composition of the mixed broadleaves (Shanshan, 2015). The fact that the Shannon index is higher for the young than the old mixed specie stand could be because the different species were planted and some species outcompeted by the pine and other come later in the succession.

5.2 Carbon stocks

Total carbon in this study is increasing rapidly as predicted and there is already a significant difference from the degraded Site to the young mixed-species stand after just 8 years. And after 33 years, the old mixed-species stand and the secondary forest have comparably similar total carbon stock. Compared to the world's average forest carbon stock 161.8 tC ha^{-1} and regional average (East Asia) 109.48 tC ha^{-1} (FAO, 2010), the restoration endeavors have in this experience come along way, the old broadleaves (180.7 tC ha^{-1}) are slightly more than the world average and the young broadleaves (62.1 tC ha^{-1}) are not too far from the regional average considering the short transition time from bare land to restored site. However both young and old mixed-species stands have are clearly lower total carbon stock than the secondary forest (271.3 tC ha^{-1}), which is comparable with the average carbon storage of Chinese forest (258.8 t C ha^{-1}) based on a areal inventory made by the Ministry of Forestry of China in 1989-1993 (Zhou *et al.*, 2000). Xie *et al.* (2012) have made a very similar study as this one in the same county (Changting) and the same conditions, and found degraded site to have a total of 13.0 ±1.3 tC ha^{-1}, 34 years old *P. massoniana* reforestation plantation to have 130.1 ± 7.2 tC ha^{-1} and secondary forest to have 166.7 ± 7.2 tC ha^{-1} (n = 3). The result for the degraded site is very similar to the findings of the present study, while old mixed-species stand and secondary forest have higher carbon stock than their study. Comparing with a study from Sichuan province measuring carbon storage from different age classes of *Pinus massoniana* plantation, there is huge difference; for 7 years old stand, the total carbon stock found is 238.1 ± 25.3 t C ha^{-1} and for 35 years old stand it was 311 tC ha^{-1} (Meta Francis *et al.*, 2015). The young mixed-species site in this study is also 7 years old but has a much lower carbon stock (62.1 tC ha^{-1}) and the old mixed-species site is 33 years old with carbon stock of 181.4 tC ha^{-1}. Their study sites are very similar regarding most factors that can affect growth and carbon storage such as latitude, climate, altitude, soil, etc., but the differing factor is the history. The sites in Sichuan do not have a recent history of deforestation and degradation (Meta Francis *et al.*, 2015) the most probably explanation of the much higher carbon stock.

5.3 Carbon pools

The importance of the different carbon pools to the total stock is different for the two stage of recovery. In the young mixed-species site, the soil is the largest carbon storage followed by forest floor detritus, understory vegetation and lastly tree biomass. That the soil would recover as much carbon in that short time was not expected, however it has a large standard deviation, suggesting spatial variability. The understory vegetation and forest floor detritus were expected to have a huge role in the carbon stock as it did. The open stand got a bit of soil preparation that leads to the possibility for them to establish and dominate the ground cover. And trees, being the last important compartment, are realistic, it is thought that growing conditions and trees generally need more time before accumulating significant amount of carbon. In the old mixed-species site, it is the opposite, trees are dominating and soils have a smaller proportion of the total carbon. It is natural that trees surpass understory vegetation and forest floor detritus with time and increasing biomass.

When comparing the different carbon pools of the total carbon stock, the difference is sometimes even larger. For the forests of China, with average of 276.3 t C ha^{-1}, the distribution in different pools is as follows: vegetation 57.1 tC ha^{-1}, soil 193.6 tC ha^{-1} and litter 8.2 tC ha^{-1} (Zhou *et al.*, 2000). The carbon stock in the biomass of the studied secondary forest and old mixed-specie stand was thrice and twice higher than the average carbon store in the biomass of Chinese forests, respectively. This difference is logical because the average for China include all stages of forest. Comparing with Xie *et al.* (2012) study in the same area, the carbon in biomass of the vegetation is similar for old mixed-specie stand and *Pinus* plantation (91.9 tC ha^{-1}) though it's younger (24 years). Secondary forest in their study differs a lot to my study; they found it to have a similar amount of carbon as the Pinus plantation (98.2 tC ha^{-1}) roughly half of what I found in my secondary forest. This could probably be due to one plot in sample had a remarkable proportion of very large trees increasing the mean of the site substantial. These large trees could also have been misrepresented as the allometric equations are not fully designed for this size of trees. The recovery of the vegetation is good in young mixed-species stand compared with a seven years old plantation of *P. massoniana* that stores 8 tC ha^{-1}; however the a nine-year old stand for the same site have 34.8 tC ha^{-1} which is not likely that the young mixed-species stand has doubled its biomass in one year (Meta Francis *et al.*, 2015). The vegetation carbon in the degraded site is more than expected, although standard deviation is as large as the mean. This indicates spatial variability in the extent of degradation between plots, with close to no vegetation in some and a reasonably amount in others.

Forest floor detritus did accumulate carbon surprisingly fast in the young stand, and the rate was comparably the same to that recorded in the old mixed-species stand and the secondary forests in just 8 years. This could probably be due to lack of decomposer. Compared to other studies, it is extremely high in all sites; for example Xie *et al.* (2012) measured 1.7 tC ha^{-1} in the litter of *Pinus* plantations. This big difference might be also related with method of collecting and what to collect; however it is such a huge part of the total carbon storage that can't be disregarded.

The carbon stock in the understory vegetation was the highest for the young mixed-species stand probably due to the low tree cover that favors the establishment of the herbaceous layer compared to old mixed-species stand and the secondary forest. Another important factor is the time of the inventory, which may not correspond to the peak production season of the herbaceous layer within the stand. Normally, monthly inventory is recommended for herbs and grasses and the peak month represent the production in the stand (Ravindranath, 2008). As the inventory for this study was conducted rather late in the season, it is possible that the peak was missed, and the carbon stock in the understory vegetation could be underestimated. For instance, Xie *et al.* (2012) measured 3.2 tC ha^{-1} in the understory vegetation in pine plantation and 6.4 tC ha^{-1} in the secondary forest for samples collected in April.

Soil carbon is the largest pool in non-degraded ecosystem, with the average for China is estimated to be 200 tC ha^{-1} (Zhou *et al.*, 2000). Surprisingly, the soil carbon even in the secondary forest soil is far from the average. It might be affected by surrounding degradation as also reported by Xie *et al.* (2012) where they measured 69 tC ha^{-1} in secondary forest. Plantations of *Pinus* on non-degraded sites with the same age as young and old mixed stands in the present have also much more soil carbon than found in the present study. Overall, the potential of soils to store carbon is related with the extent of degradation of the site prior to restoration. The profile of carbon present in the soil at different depths shows a different pattern between the different sites, the norm is to have a drop off in carbon with greater depths like in the secondary forest. The other three have a very small difference between the three depths. This might be explained by the difference in topography within the site; the secondary forest lies mostly on flat area while the other sites had medium to steep slopes.

Carbon accumulation in vegetation can vary depending on the species, site conditions and previous degradation history. A review of tropical plantation found that during the first 20 years of plantation establishment, accumulation of carbon can range from 0.8 to 15 tC ha^{-1} yr^{-1} (Lugo *et al.*, 1988). For pine plantation in southern China, the accumulation rate was 4.9 tC ha^{-1} yr^{-1} for the whole ecosystem, of which 3.8 tC ha^{-1} yr^{-1} in the biomass and 1.1 tC ha^{-1} yr^{-1} in the soil (Xie *et al.* 2012). For the total ecosystem, the rate is high in both young and old mixed-species stands in the present study while the rate of carbon accumulation in the biomass is comparably the same as the study by Xie *et al.* (2012).

5.4 Total Nitrogen stock

Studies focusing on total nitrogen reported similar result on the nitrogen level. Xu *et al.* (2014) measured the total nitrogen in the top soil (0-10 cm) for a site similar to the degraded site in this study and found the percentage of nitrogen to be 0.037 ± 0.003 and for a richer area with more ground vegetation and trees, the nitrogen percentage was 0.075 ± 0.019 .The amount of nitrogen presented in Figure 7 are in tN ha^{-1} and corresponds to a percentage of 0.032 for the degraded site and 0.058 for young stand in the top soil. For old stand, it is 0.067% and the secondary forest has a total nitrogen stock of 0.13%. From an agriculture perspective, Bruce *et al.* (1982) divided the total nitrogen percentage into five classes from very low to very high and all my values are in the very low < 0.05 or low 0.05-0.15. While the nitrogen need of agricultural crops and forest trees might be different, the result highlights that the soil fertility is still low in all sites. However, there is a significant difference in nitrogen stock in the top soil between the degraded site and the restored sites; suggesting that the nitrogen level is recovering. The lack of significant differences in total nitrogen stock in the lower parts of the soil might be due to the quantity and quality of litter fall and slow rate of its subsequent decomposition and incorporation into the soil system.

There are significant differences in the C/N ratio between degraded and restored sites, but the overall mean C/N ratio was relatively lower (less than 10). This fact could be associated with low levels of fresh organic materials incorporated into the soil in the degraded site where the vegetation cover is very limited or totally absence. It should be noted that spatial variability in the vegetation cover has been noted among the different plots in the degraded site during the fieldwork.

5.5 Limitation and of the study

There is a lack of relevant studies written in English which is a limitation of the study. Most of the English written studies indicate (if looking at their reference list) that there is much more relevant literature however all in Chinese. This has limited my literature review and possibility to compare my result. A well-documented history of what have been done in the old mixed-species stand was not possible to obtain and I had to trust verbal sources.

6. Conclusion

Forest restoration has become more important as we understand what ecosystem services it provides and what we need. Carbon storage in terrestrial ecosystem and mostly forest has an increasing importance today when the effects of global warming have become visible. Large degraded areas have undergone restoration in China and elsewhere so as to restore forest and its services; however it is important to reflect on what kind of forest we are creating. The restoration project in Changting involved both active restoration (mixed-species planting on degraded sites) and passive restoration (exclosure of further disturbance from recovering secondary forest). Such restoration approaches have shown promising results in recovery of both structural (vegetation) and functional (nutrient cycling) attributes of the ecosystem while at the same time restoring some aspects of the biodiversity. The results from this thesis work show:

(1) drastic increasing in tree species richness
(2) good recovery of carbon with the soil being the dominate pool in the early stage of recover and tree and other vegetation in the later stage
(3) good recovery of nitrogen stock in the top soil.

The result of the carbon accumulation is comparable to those of pure *P. massoniana* while at the same time storing a larger variety of species. It probably has a more diverse stand structure that could support more ecosystem services. There are a lot of factors not included in this thesis that could be of interest for further research, such as restoration cost, socio-economic impacts of the restoration endeavor on the local communities and other ecological and social benefits that can be accrued from restored forest landscape.

Acknowledgements

I would like to thank Professor Ma Xiangqing dean at the Colleage of foresty at the Fujian Agriculture and Forestry University, Yan Yao and all the other students and teachers who help me during field work, lab work and making my stay in China as good as it could ever be.

Thanks to my supervisors Mulualem Tigabu and Per Christer Oden without their contacts and help I would never got this opportunity to conduct my master thesis in China. They have supported and guided me throughout the process of this thesis. Finally, I thank Sida for the MFS scholarship for financial support for this study.

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Appendix

Appendix I: All species of trees and shrubs found in the four different sites and the total number of individuals recorded for each species in all plots n=6 (n=5 for secondary forest).

Family	Species	DS	YS	OS	SF
Altingiaceae	*Altingia gracilipes Hemsl.*	-	-	-	28
Myrtaceae	*Baeckea frutescens L.*	1	-	-	-
Theaceae	*Camellia oleifera Abel.*	-	-	13	-
	castanopsis fargesii Franch.	-	11	-	11
	Castanopsis fordii Hance	-	-	-	2
Lauraceae	*Cinnamomum camphora (L. Presl.*	-	6	-	5
Cornaceae	*Cornus stolonifera var.Glaviamea L.*	-	-	7	-
Anacardiaceae	*Cotinus coggygria Scop.*	-	-	-	1
Cupressaceae	*Cunninghamia lanceolata (Lamb. Hook.*	-	13	101	-
Fabaceae	*Dalbergia hancei Benth.*	-	-	-	5
Hamamelidaceae	*Distyliopsis laurifolia (Hemsl. Endress*	-	-	-	2
Elaeocarpaceae	*Elaeocarpus chinensis (Gardn. et Chanp. Hook. f. ex Benth.*	-	3	-	-
	Elaeocarpus sylvestris (Lour. Poir.	-	36	-	-
Pentaphylacaceae	*Eurya loquaiana Dunn*	-	-	42	-
Aquifoliaceae	*Ilex asprella (Hook. & Arn. Champ. ex Benth.*	-	-	-	2
	Ilex kwangtungensis Merr.	-	-	5	2
	Ilex pedunculosa Miq.	-	-	-	10
	Ilex pubescens Hook.& Arn	-	-	3	2
	Ilex triflora Blume	-	3	-	5
	Lespedeza bicolor Turcz.	-	36	-	-
	Lindera aggregata (Sims Kosterm.	-	-	4	4
	Liquidambar formosana Hance	-	76	1	-
	Lithocarpus corneus (Lour. Rehder	-	-	-	3
	Lithocarpus glaber (Thunb. Nakai	-	-	-	1
	Loropetalum chinense (R. Br. Oliv.	-	-	-	7
Sabiaceae	*Meliosma rigida Sieb. et Zucc.*	-	-	-	1
Magnoliaceae	*Michelia maudiae (Dunn Figlar*	-	7	-	-
Rubiaceae	*Mussaenda pubescens Dryand.*	-	-	-	2
	Phoebe zhennan S.K. Lee & F.N. Wei	-	-	1	1
Rosaceae	*Photinia davidsoniae Rehd. & Wils.*	-	-	-	1
Poaceae	*Phyllostachys heterocycla var. Pubescens (Carr. Mitford*	-	-	-	4
Pinaceae	*Pinus massoniana Lamb.*	63	160	151	11
	Randia cochinchinensis (Lour. Merr.	-	1	-	13
	Rhaphiolepis indica (L. Lindl.	-	1	-	-

	Schima superba Gardn. & Champ.	-	9	117	45
Symplocaceae	*Symplocos caudata Buch. -Ham. Ex D. Don*	-	-	4	14
	Symplocos confusa Brand	-	50	-	-
	Tarenna mollissima (Walp. Rob.	-	-	-	2
	Toxicodendron succedaneum (L. Kuntze	-	-	1	2
	Uncaria tomentosa (Willd. DC.	-	-	-	3
Ericaceae	*Vaccinium bracteatum Thunb.*	-	2	-	-
Adoxaceae	*Viburnum fordiae Hance*	-	-	1	-
	Unidentified	-	2	19	8

Appendix II: Carbon storage for the different pools of the ecosystem presented in tons carbon per hectare. Standard deviation inside the brackets and significant difference for the letters on the same row ($p<0.05$)

	Degraded site	Young mixed-species	Old mixed-species	Secondary forest
Tree above ground	0.9 ± 0.7 a	4.9 ± 0.7 b	86.9 ± 21.0 c	144.8 ± 116.0 c
Tree below ground	0.2 ± 0.2 a	1.3 ± 0.2 b	22.6 ± 5.5 c	37.6 ± 30.2 c
Forest detritus	3.7 ± 3.2 a	12.6 ± 2.5 b	17.4 ± 2.2 bc	19.6 ± 5.1 c
Understory vegetation	2.3 ± 2.3 a	8.2 ± 3.0 b	3.9 ± 0.7 a	4.3 ± 1.4 a
Deadwood	0	0.002	0.6	3.8
Soil	6.6 ± 3.0 a	35.1 ± 21.1 ab	49.9 ± 21.3 b	65.0 ± 12.3 b