Czech University of Life Sciences Prague

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Environmental analyses of Eucalyptus globulus trees in Galicia

Master Thesis

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Prague 2016

Author's declaration

I hereby declare that I wrote this diploma thesis independently, under the direction of Ing. Vladimír Janeček, Ph.D. I have listed all literature and publications from which I have acquired informations and that the material has not been submitted, either in whole or in part, for a degree at this or any other university.

Prague, 12th of May ....

Abstract

The current state of the *Eucalyptus globulus* (Tasmanian blue gum) tree cultivated in Galicia (region situated in North-West of Spain) points out more then one alarming fact. There is a chain of consequences that begins from the moment the eucalyptus tree is planted; there is no control over its extensive and unplanned spreading throughout the landscape, the forests aremissing proper management, the frequent threat of wildfires and subsequent soil erosion is a consistent problem, and there is ecosystem degradation and a loss of biodiversity. These are just the most important problems linked to the intensively replanted *E. globulus* tree, because the consequences are affecting the whole environment, as well as the social welfare and economic situation. This enormous topic offers me all of the mentioned facts and a very rich amount of quality references to support them , which are used for the presentation of the actual situation in the methodology chapter. The following chapter of potential solutions indicates that fire prevention is a priority, and then explains how to proceed after the fire occurs depending on the scale of the production site. The next measures are focused on the introduction of native trees and bush species, increasing of biodiversity and general environmental quality at frequently used eucalyptus production sites. Considerable attention is given to land management as a fire prevention tool on a wide scale, therefore outside of the production site, and also how to refresh rural life and its economy, because the rural environment is the key area for eucalyptus cultivation and the related threat of fire ignition. So, the whole concept of this thesis paper is to explore and introduce the problems, characterize the study area and discuss the methods and application of already existing measures and treatments, which should increase environmental conditions, improve social welfare and explore the alternative modern methods of silviculture practices designed for timber and non-timber production.

Key words: environmental impact, fast growing plantations, *Eucalyptus globulus*, non-timber forest products

Abstrakt

Současnou situaci ohledně kultivace *Eucalyptus globulus* v Galicii (region ležící v severo-západním cípu Španělska) doprovází mnoho alarmujících skutečností. Jedná se o řetězec faktů, který začíná již u jeho vysazení, dále pokračuje přes jeho nekontrolovatelné extenzivní šíření krajinou, chybějící odpovídající obhospodařování, v návaznosti na to častý výskyt požárů a s tím spojená eroze půdy, degradace ekosystémů a celková ztráta biodiverzity. Toto je výčet těch opravdu nejpodstatnějších problémů spojených s kultivací *E. globulus*, jejichž následky ovlivňují životní prostředí, včetně sociálního blaha a též konkrétní ekonomickou situaci. Toto roszáhlé téma mi poodkrylo zmíněné skutečnosti a k tomu velice obsáhlé množství literatury, která se jimi zabývá, ta je použita k nastínění vážnosti situace v kapitole metodiky. Následující kapitola návrhů řešení primárně zdůrazňuje pořární prevenci, dále jak ošetřit svoji produkční plochu v případě, že již byla zasažena požárem, další opatření se týkají znovu zavedení domácích dřevin, navýšením biodiverzity a celkové kvality životního prostředí na intenzivně využívaných plochách, určených k produkci Eukalyptu. Nezanedbatelná pozornost je věnována proti požárnímu způsobu obhospodařování krajiny v jejím širším měřítku, tudíž za hranicí naší produkční plochy, což navazuje na část týkající se oživení venkova a jeho ekonomiky, protože hlavně krajina venkova je klíčovou pro kultivaci Eukalyptu a právě v ní dochází ke většině požárů, které tak rozsáhle ovlivňují místní životní prostředí. Celkový koncept práce se tedy zabývá uvedením do problematiky, charakteristikou studovaného území Galicie a aplikací již existujících návrhů řešení v krajině, které by měly zapříčinit zlepšení podmínek životního prostředí, přinést celkové sociální blaho a poukázat na alternativní a moderní způsob lesního hospodářství, který zohledňuje těžební i netěžební zdroje lesa.

Klíčová slova: dopad na životní prostředí, rychle rostoucí plantáže, *Eucalyptus globulus*, netěžební produkce lesa

Acknowledgements

I am thankful firstly to my supervisor Ing. Vladimír Janeček, Ph.D. for that he accepted my idea for master thesis, then to Juan Daniel García Villabrille from University of Santiago de Compostela, department of Agricultural and Forestry Engineering for his time and valuable suggestions, at least to Ing. Martin Štrobl for his distant help in Czech Republic.

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1 Introduction

Forests are fundamental to the well-being of humanity, society and the environment. Forests not only provide raw materials for rural livelihoods and industrial manufacturing, but also contribute to improved quality of life for urban dwellers around the world. Specifically, apart from producing fuelwood for energy purpose, timber for construction and wood for processing into a variety of products in satisfying a long list of human needs, forests supply an array of non-timber products. As distinct ecosystems, forests provide clean air, wilderness attributes, wildlife habitat, water regulation functions, carbon storage, and spiritual respite. In particular, forests provide an ideal setting for outdoor recreation *(Wang, 2013)*.

Eucalyptus globulus (Tasmanian blue gum) together with *Pinus pinaster* (Maritime pine) are the most spreaded kind of trees for wood production in the sector of forestry for whole region of Galicia in the north-west part of Spain, the added value of genus *Eucalyptus* has traditionally been its wood for the production of paper. Thus, the studies related to this species have been focused on discovering, from a forestry point of view, the species that maximize the production of wood with the highest possible density *(Madgwick et al., 1991; Liu et al., 1993)* and *Turnbull (1999)* says that success of Eucalypts can be attributed to their fast growth, coppicing ability, wide adaptability to soils and climate conditions. Eucalypts, chiefly like *E. globulus*, *E. grandis* (Rose gum), *E. nitens* and *E. Camaldulensis* (River red gum) have become the most widely planted hardwood species in the world, mostly for paper production *(FAO, 2010)*. *Eucalyptus globulus* being the most common species, but with an increasing proportion of *Eucalyptus nitens* for plantations in Galicia, which is grown successfully as a frost tolerant species and is better adapted to the negative influence of *Gonipterus scutellatus*. Both species belong to the subgenus *Symphyomyrtus*, known to produce larger average tree sizes and to be more productive than species of the subgenus *Monocalyptus (Davidson and Reid, 1980; Turnbull et al., 1993)*.

Commercial eucalypt plantations may cover over 20 million hectares in the year 2009 worldwide *(Trabado and Wiseman, 2009)* a figure that is more than twice that was recorded less than 15 years ago *(FAO, 1995)*. Already in the year 1998, fast-growing eucalypt stands supplied 10 million m^3 of wood per annum to pulp factories in whole southern Europe *(DIEF, 2000)*. The total area occupied by eucalypt plantations in southern Europe is approximately 14,000 km^2 for year 2000 *(Sims et al., 1999)*. However, the expansion of eucalypt plantations has raised concerns regarding ecosystem degradation (e.g. loss of biodiversity) and Eucalypts have become a major source of conflicts between foresters and conservationists in many countries. Studies on the effects of eucalypt plantations on biodiversity are surprisingly scarce considering *(Temes et al., 1985; Basanta et al., 1989)* the spread of these plantations around the world, but some point to lower biodiversity in eucalypt plantations as compared to other communities of production plantations *(Pina, 1989).*

Hand in hand with non-effective management of eucalypt plantations goes fact of wildfires in Galicia, which decrease a productivity and also have negative effect on soil qualities, erosion, ecosystem degradation with direct influence on socio-economic situation. Galicia together with north of Portugal are the European areas most affected by forest wildfires, and worldwide they are among the areas with the greatest number of fires per hectare and inhabitant *(Carballas et al., 2009*). The major problem in Galicia is the economic cost of the wildfire prevention due to the extent of the area to be treated and the small size of the plots, but important amounts of money are also needed for suppression and restoration. For example forest fire services faced a very difficult situation in 2006, characterized by increasing fuel accumulation, a huge number of simultaneous fires close to towns and villages, and sometimes a lack of coordination in the large fires among administrations providing different resources *(Amil, 2007b).*

Most of these plantations are on steep slopes, shallow and acidic soils developed on granitic bedrock, in an ocean-influenced coastal area with a mild, humid climate. These eucalypt stands, characterized by their high growth rate (the highest in western Europe forests), are managed on short rotations (10 – 15 years) using mechanized skidding and intensive logging slash manipulation after clearcutting. Harvesting practices can increase the potential for sediment production through soil alteration and forest floor disturbance; this in turn, may cause an increase in runoff and in soil losses *(Blackburn et al., 1986; Beasley and Granillo, 1988; Rab, 1994; Castillo et al., 1997; Edeso et al., 1999)*. These facts are the main once causes for closly related social and economical problems, which are with fast growing plantations negativelly affecting more and more dwellers of Galicia and further more than there.

2 The aims of the thesis

Fires, soil erosion and socio-economic problems caused by wrong forest management and strict policy made for Eucalyptus plantations, are studied for to understand their consequences. Then based on known facts are prepared solutions for alarming results of existing studies. Solutions will be focused on fire prevention, soil erosion measures, increasing of native tree species composition and at least to optimization of growing models for timber and non-timber production; it may involve alternative income for existing stakeholders, which situation is controled by ENCE company, leader and main policy maker of Eucalyptus timber production in Galicia. Way of integration into the practice will be discussed for all studied solutions.

3 Literature research

Until the 1960‘s, forestry was a contracting sector, in favor of agriculture and cattle farming. The growth of the population increased the pressure on forestland to sustain the growing agricultural and cattle farming sector. However, migration towards urban areas, together with changes in farming practices, made these lands less needed for agricultural purposes, so the landowners and local authorities proceeded to plant trees *(López, 1990)*.

In order to conform to the needs of particular sectors of the forest industry, mainly pulp and paper manufacturers, Public Administration promoted even-aged (Photo 1), monoculture stands of fast-growing species in short-rotation plantations with intensive management (Photo 2). More specifically, the National Forest Estate Act (NFE) scheme assigned productive or economic objectives to 75 % of the national afforestations conducted in 1953 *(Groome, 1990)*. The productive species included in the forest model implemented under the NFE scheme in the Cantabrian and Atlantic Coasts belonged mainly to genera *Eucalyptus* sp. And *Pinus* sp. Similarly, industrial

Photo 1. *Approximatly 3 years old Eucalyptus globulus trees, even-aged stand at the site close to Santaigo de Compostela.*

Photo 2. *Even-aged production site of Eucalypts, which could be few years to harvest. Photo shows the density of planting at the field and uniformity of genus Eucalyptus.*

initiatives linked to fibre and particleboard production arose and gained strength during the second half of the 20th century *(Rico, 1995; García and Groome, 2000).*

The reforestation was mostly done with *Pinus pinaster* at first, and with plantations of *Eucalyptus globulus* later. Most commonly replaced communities are natural forests, shrublands and pine plantations, directly or indirectly *(Stephens et Wagner, 2007).* An increased demand for wood has led to rapid expansion of plantations of fast-growing forest species in some regions of Spain and Portugal, where more than 1 000 000 ha of land have been planted with such species in the last decades (Figure 1). Currently, both species make up 85 % of the timber supply in this region *(Goméz et al., 2011; D.G.C.N., 2000).*

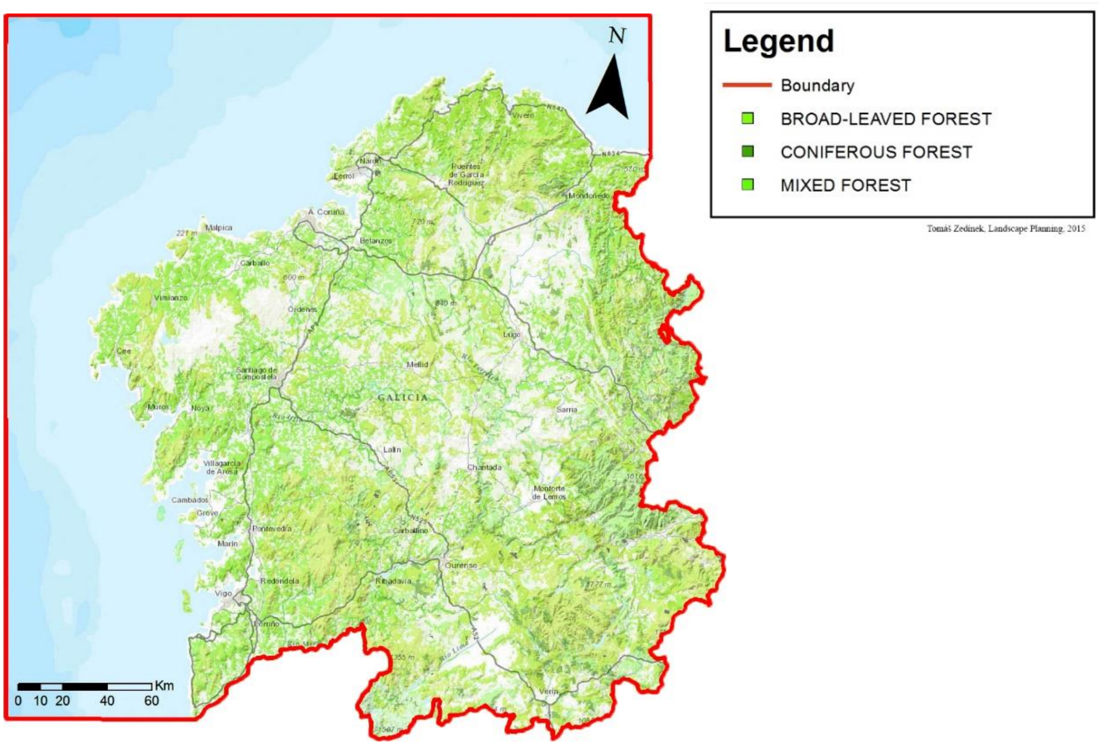

Figure 1. *Forest land in Galicia, which cover aproxximatly 69 % of this region (ArcGIS, 2015).*

On small private forest estates, which represent 63,7 % of the forest land, excessive fragmentation of land (e.g. farms with an average size of 1,75 hectares are frequently divided into 7 – 8 separate parcels) prevents the development of management plans that would ensure profitability and a regular flow of timber also than fact since most individual forests in Galicia are privately owned (Photo 3), the

Photo 1. *Typical view of privat land ownership and way of different even-aged plots of Eucalypt.*

government does not have direct control of the forest management undertaken in them, forest management if there is any, is up to the individual owner *(Robak et al., 2012)*. In collective properties owned by neighbourhood communities, which represent 33 % from this private estates of forest land and have an average extension of 225 hectares *(Xunta de Galicia, 2006)*, productivity is usually low as planting distances are often inadequate, fertilization treatments are relatively new and research on tree genetic improvement in order to find the best clones has been limited, because genetically improved stock is not yet available for general use in Spain *(Brañas et al., 2000)*. Although some collective properties are managed by the Regional Forest Service through some management plan, no optimal management tools for strategic planning of eucalypt plantations have been developed in this region yet *(Balteiro et al., 2009)*.

This fragmented ownership pattern has made it difficult to promote sustainable forest management (SFM) and the development of the sector. Only a small portion of the forested land is managed in a patently sustainable manner, which does not bode well for the future of industrial forestry given the pressure for certified SFM from governments, the general public and the forest product marketplace. This makes it difficult to justify public and private investment in forestry, which in turn impedes investment in forest industry modernization. If the industry is not modernized, the degree of "value – added" processing will remain low, with most raw production sent to other regions for processing *(Robak E. et al., 2012)*.

3.1 Current management

Most Eucalypts are planted by forestry companies on existing forest soils, in areas with a range of limitations for forest productivity (Photo 4), although there is an increasing incidence of landowners establishing eucalypt plantations on abandoned agricultural soils, which are highly productive. The plantations are managed in short rotations, usually of 12 – 15 years. It is very hard to get the information about exact number of rotations at the field, in cases of private ownership it is up to the person, who is managing his forest land and in case of companies, there is an example of ENCE company, which starts to mark the rotations and count them since few years ago *(García, 2015)*. The management is usually intensive and includes clearing of

Photo 2. *Steep slope and low qouality soils are not limitation for interest in timber, as you can see this is new replanted site by seedlings of Eucalypt. It could be possibly first rotation at the field.*

Photo 5. *Example of containerized seedling plant of Eucalypt at the same field as is presented next to (Photo 4), seedling is approximately 20 cm high..*

brushwood, mechanical site preparation and plantation of containerized seedlings (Photo 5). In many stands, fertilization is carried out at establishment. The most widely employed site preparation technique is deep tillage, whereas in the steepest areas, preparation of planting holes is preferred. On low slopes, discharrowing or mounding may also be used. To facilitate access for planting and to speed up decomposition, chopping rollers are often used to break up the logging residues. A very intensive technique consisting of pushing the logging residues and humus layer to the side of the site (e.g. windrowing) is sometimes carried out.

Stands are frequently regenerated by coppicing and three coppice crops can usually be obtained before loss of efective productivity (Photo 6). Coppice system in even-aged stands is developed from firstly planted container seedlings, which are clearcutted at the end of the first rotation interval and repeated crops secured from stump-sprouts (Photo 7) are coppiced on succeeding rotations. Examples of this sylvicultural system can be also founded in Brazilian plantations *(Nobre et Rodriguez, 2001)* in Portugal *(Falcão and Borges, 2002)* and in the rest of Spain *(Riesgo, 2004)*. The logs are usually debarked in the timber factory. Although in most

Photo 6. *Nice example of four sprouts growing from one stump, the most appropriate new shots are preserved for to achive the highest possible amount of timber.*

Photo 7. *As you can see, that light green new shot, growing straight up from the branch of Eucalypt is an example of regrowing possibilities of this genus.*

cases the logging residues are retained on site, some site preparation methods involve them being burned or, rarely, removed along with the litter layer. Logging residues are also increasingly used as a source of fuel and raw material for woodchip production *(Merino et al., 2005).*

However, these management plans do not consider the optimum length for one full plantation cycle that maximizes forest profitability *(Balteiro et Rodriguez, 2006)* neither do they formulate the area control method through any mathematical programming model to derive the schedule for regeneration harvests *(Balteiro et al., 2009).* Eucalypt production differs according to the soil conditions *(Brañas et al., 2000)* and also to the type of silvicultural management, such as fertilization at establishment and vegetation control *(Río et al., 1997).* Productivity ranges from 10 m^3 to 40 m^3 / ha / year, with an average value of 20 m^3 / ha / year, *Riesgo (2004)* says that in the best sites of the region, timber yield may reach up to 50 m^3 / ha / year, which is uncommon in other productive forests across whole Europe. Despite their high productivity and the importance of eucalypt to the local wood industry, the management of these plantations is far from optimal *(Robak et al., 2012).* So, because of that reality, foresters and forestry companies are looking for some ideal growth model, kind of optimization techniques, set of tools that facilitate optimal strategic planning by solving issues such as determining the optimum length for one full plantation cycle for coppice forests (e.g. the number of crops, or rotation intervals and the corresponding rotation ages before a forest stand is reestablished by planting), scheduling regeneration harvests to best meet multiple management goals, determining the thinning intensity in even-aged stands *(Borges et al., 1999).*

3.2 **My traineeship in Galicia**

I participated in the process of cultivation of Eucalyptus trees in Galicia thanks to my Erasmus Internship, exactly in Santiago de Compostela. I found a company called Servicios Agrarios Cacho Roberto S.L. and there I spent three months working about Eucalyptus trees. We were able to realize all the necessary steps for cultivation, from the preparation of site until the last step of cultivation; i.e. harvest. So, I will try chronologically explain all the steps, for to clearly understand whole cultivation process.

Photo 8. *Photo of my colleague driving our small tractor with mulching machine behind. This equipment is enough for cleaning of small bush and grass.*

Photo 9. *This is a bigger alternative of mulching machine for cleaning the higher shrub, stumps and also smaller trees with diameter of trunk until 25 cm approximately.*

We should start with preparation of the site for new plantation. There exist two cases, first one is that, where did not grow Eucalyptus trees yet and the other case is about the second, or other more rotation at the place. It’s supposed to be any agricultural land for our first case, which is firstly cleared from low shrubs and grass fields by chain mulcher (Photo 8) and more complicated fields with higher trees and mix of forest stand were cleared by machine TMC Cancela model TFR 225 (Photo 9). When we cleared enough our area for planting (Photo 10), then came the moment for heavy machinery again with ploughshare (Photo 12), by it were done first paralel furrows with three meters distance, spreaded all over the field (Photo 11).

Photo 10. *It was a forest at this place, combination of Eucalyptus and Pine mix stand with under layer of shrubs and grass species. Cleaning by mulching machines came after the harvest and unload of timber from there.*

Photo 11. *Example of cleared plantation with parallel furrows. Alternative purpose of those furrows is keeping rain water for trees, such a water channel.*

Next step was a process for five persons in our case. We made two paralel lines all across plantation in right angle to the existing furrows by the ropes in three meters distance again, as a leading lines for planting process, because final form of site for planting is done in squares, which correspond to 3 per 3 meters size.

We were planting in each node of rope and furrow Eucalyptus seedling, high humidity for root complex of each seedling is very important for all the process (Photo 13). First person is making hole for the tree, then the same person is putting small amount of basic mineral nutritions (N-P-K) to the hole, another is filling it by water and the last person is coming with hand pot of water filled with Eucalyptus seedlings and planting them into the prepared holes.

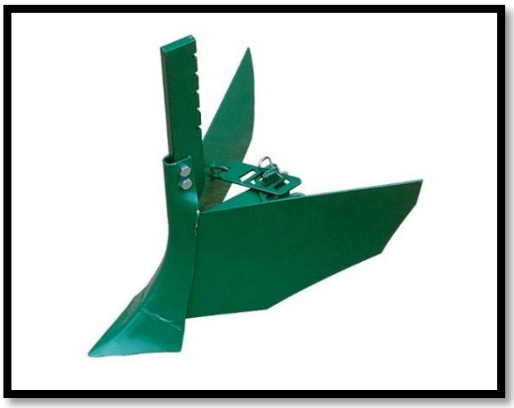

Photo 12. *Basic ploughshare for preparation of first paralel furrows at the new established plantation (www.traktory-sedlcany.cz).*

Photo 13. *Water barrel filled by rain water, which is usefull for humidification of our plastic pots full of seedlings before to plant them.*

***Photo 14.** Some of certificated plastic pots full of Eucalyptus seedlings, ready for to be planted.*

***Photo 15.** Example of enough cleaned plantation of Eucalyptus trees, which was done by mulching machine TMC Cancela between the tree lines and by brush cutters in the line between the trees.*

We were using certificated seedlings in plastic pots for nursery plants (Photo 14) and water which we used, was thanks to the good quality water sources from natural streams around the plantations. They were replanted if some of them get dry, or die for any reason and this replantation was done during other visit in the season. There was a favor of rainy weather for planting, because of the higher humidity of soil. Trees which stay alive over the first season are strong enough for next year. There are not any animals and insects, which are able to badly affect baby trees and all this leads to high success of growth.

Of course each well prepared plantation needs basic maintenance during all the seasons until the time of harvest. First part of care is cleaning from all greenery at the site, this could be done after the spring and during the autumn. Clearing process was done by mulching machines between the tree lines and by brush cutters between and around the trees (Photo 15). Second part of maintenance is coming approximately with third year of cultivation, when the trees are high enough and we are able to cut all the small branches by chain saw, purpose of it is to have done right size of the tree crown and keep the trunk without nods of branches, they are decreasing the final price of timber.

Harvesting period is closely related with conditions at the plantation (e.g. genetic qualities of planted trees, weather conditions as the soil quality and human effect of maintenance), usually it is about 12 – 15 years since the trees were planted. Cleaning of other greenery at the site is important step before the harvesting. Cutting of the trees is done by chain saws as it is usual. Person who cutted the tree is also cutting the branches all along the length of the trunk and that of course too. There is a person, who is responsible for gathering the branches and the trunks at less points at the field as is just possible for better access of harvestor, that is loading and concentrating all timber for truck transportation. Timber should be situated at well accessible point for the truck. All the residuals were left at the plantation, then came moment for our mulching proces again as it is mentioned in the text above, when all the timber is unloaded from there and the history of all this cultivation proces can be repeated.

3.3 **Wildfires**

Unfortunately, fire is a recurrent and serious threat to the forest and wooded area of Galicia, leading every year to important environmental, social, and economic damage (Photo 16). Wildfires cannot be considered occasional events in Galicia. As is showen in graph (Figure 2), number of outbreaks and area burned from 1985 to 2008. The annual average of outbreaks was 8000, which is a particularly high value. Fire occurrence has increased from about 4000 annually in the middle of the 1980‘s to

Photo 16. *Huge affected area by wildfire in the year 2014 close to the Santiago de Compostela, next to the Monte Pedroso. It is not just the ecological, but also economical and social problem.*

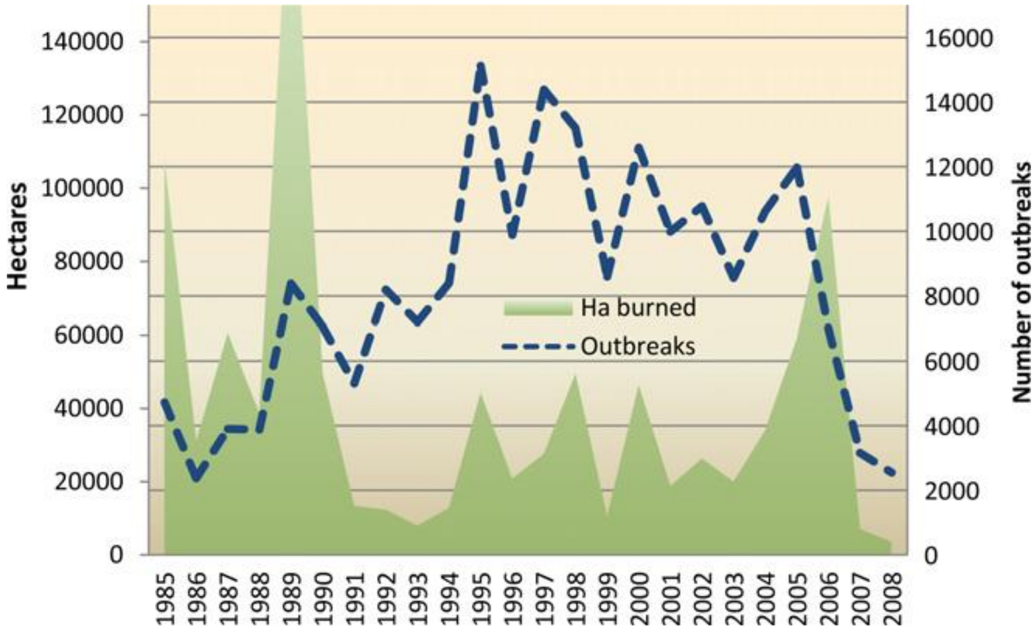

Figure 2. *Number of outbreaks and area burned from the year 1985 to 2008 (MARM, 2009).*

10,000 at the beginning of the 1990's. Later, it has been stabilized around 10,000 during the period 1994 – 2006, and in 2007 and 2008 the wildfires decreased. Galicia represents approximately 46 % of the fire outbreaks in all of Spain for the period of years 1985 till 2008. Furthermore, for the majority of the years the area burned was over 30,000 hectares *(MARM, 2009)*.

Most of the wildfires are human induced and enhanced by gradual land abandonment and the favorable weather conditions (e.g. hot temperatures, dry conditions and strong winds). All these factors have allowed fires to spread quickly and favored the destruction of a large forested area. The devastating numerous fires set in Galicia, have motivated an urgent social consciousness of the problem and heated scientific debate *(Amil, 2007a,b; Balteiro, 2007; Fernandes, 2008)*.

Exact problematic of fires in relation with *Eucalyptus globulus* in Galicia was nicely explained by *Amil (2007b)* in case of one heated scientific discussion, like a reply for Dr. Diaz. Let's say more than half of the total wooded-land in Galicia is covered by *P. Pinaster* and *E. globulus*. Ecological terms such as „alien species" or „pyrophytic species", there is also a significant literature about alien species and specifically about the effect of invasive alien species on fire regimes *(Brooks et al., 2004)*. Furthermore, „pyrophytic species" are those species that are competitive advantaged by landscape fires. Some of them can be highly flammable (pyrogenic), demographically advantaged by landscape fires (pyrophilous), or both. For example, the economic and environmental damages caused by the forest fires in Galicia during 2006 have been evaluated, concluding that the total economic value lost amounts to more than 600 millions of euro in the short run *(Barrio et al., 2007)*. Post-fire regrowth at the eucalyptus site largely consists of eucalyptus resprouting from the charred stumps (Photo 18 and 19). Six months after fire the stems had reached heights of 1 – 1,5 m and the understorey vegetation remained sparse and low throughout the monitoring period, because of the allelopathic effects of the eucalyptus and the inability of other plants to compete with its rapid growth *(Andrew et al., 1999)*. Understorey fuel (Photo 17) quantities in unburnt eucalyptus was measured by loads of ca. 60 – 80 t / ha *(Shakesby et al., 1993)*.

Photo 17. *Post-harvesting litter and residues which are highly flammable. In the top left corner you can see young seedling of Eucalypt. Exactly these litter rest from last harvest could be great base for a fire during summer season..*

Photo 18. *As you can see from the base part of stump are growing new sprouts, tree was affected by wildfire that year.*

Photo 19. *Even-aged stand affected by fire, all trees are regrowing by new shots from their stumps at the whole site. Coppicing system is based on this attribute of Eucalypt.*

3.4 **Soil and erosion problems**

Forest soils (Photo 20 and 21) in northern Spain are strongly acidic and contain low levels of extractable Ca, Mg, K and P *(Guitián, 1982; Bará and Toval, 1983; Díaz and Gil, 1984; Macías and Calvo, 1992)*. The low reserves of elements in forest soils are attributed to high leaching, slow weathering of the minerals in the parent material *(Macías and Calvo, 1992; Dambrine et al., 2000)* and also to their high capacity for fixing P *(Rodeja and Gil, 1997)*. The success of *Eucalyptus globulus* in northern Spain is partly due to the favourable climatic conditions, but also with its tolerance to acid soils, low requirements of P, Ca and Mg *(Calvo and Anta, 1992; Attiwill and Adams, 1996)*. However, analyses carried out in other studies *(Brañas et al., 2000; Español et al., 2000)* revealed low foliar levels P, Ca and Mg, as well as large amounts of nutrients exported from the site during harvesting compared with the nutrient storage of the soils, especially in shallow and stony soils with low soil reserves *(Brañas et al., 2000)*.

Photo 20. *Example of compacted and stony surface with a bit of post-harvesting litter as a soil for eucalyptus trees at the established plantation.*

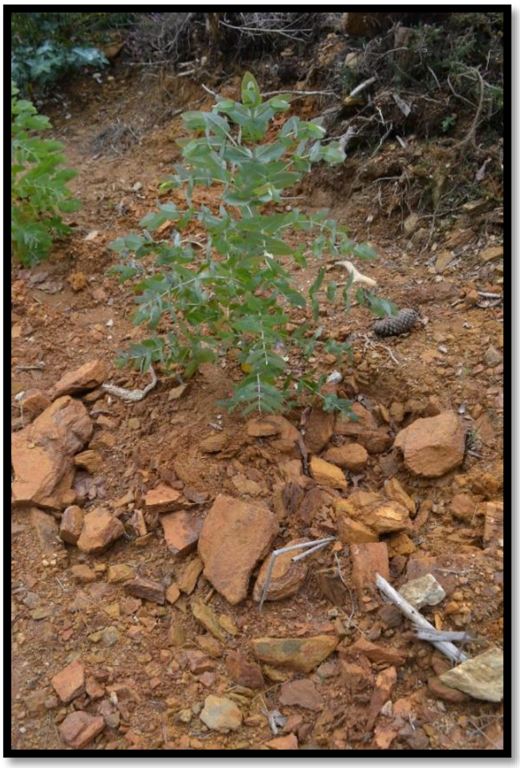

Photo 21. *Young seedling of Eucalypt planted in the stony and acidic soils.*

Most of the plantations are on the steep slopes, mean the combination of wildfires described in text above and cases of high rain intensity during the autmn and winter seassons causes substantial erosion effect. Wildfire effects on the soil environment are highly variable; however, in general, fires cause partial or complete combustion of organic matter, deterioration of soil structure, depletion of nutrients through volatilization and leaching, altered aggregate stability and water repellency, together with marked quantitative and qualitative alterations of soil microbial communities *(Neary et al., 1999; Fernández et al., 2001; Certini, 2005; Carballas et al., 2009; Raviña et al., 2010; Almendros and Vila, 2012; Holden and Treseder, 2013)*. Most of the nutrients are lost in the first months after the fire (*Ferreira et al., 2005a; Prats et al., 2014a; Spiegel and Robichaud, 2007*). Fact, that eroded soil losses tend to rise sharply immediately after forest fires but decline rapidly thereafter *(Swanson, 1981; Fierros et al., 1987; Sevink et al., 1989; Imeson et al., 1992; Shakesby et al., 1993)* doesn't simplify the situation, because in combination with high annual rainfall index 1865 mm *(Regueira et al., 1996)* there are still huge soil losses in combination with actual conditions at the field (e.g. stony soils and steep slope). The processes connectivity at slope level and their impact on the transmission of water and sediments from the slopes to the water courses plays an important role in the degradation of burned areas (*Ferreira et al., 2014*). *Fernández et al. (2004)* acknowledge also that harvesting practices may sharply cause and increase runoff, soil losses and this post-harvesting erosion may exacerbate nutrient losses with consequences on long-term soil productivity. Nutrient balance studies *(Dambrine et al., 2000; Gómez and Calvo, 2001)* have shown that losses of nutrients due to harvesting can lead to decreased reserves of soil available limiting nutrients, which could affect the long-term productivity of timber, if they are not replenished through an adequate fertilizing programme.

3.5 *Gonipterus scutellatus*

Gonipterus scutellatus is a weevil that has become a pest in most Eucalyptus plantations in Africa, America and Europe. The Eucalyptus snout beetle was introduced accidentally into the Galicia in 1991, this snout beetle is of Australasian origin and feeds specifically on Eucalyptus. Both the snout beetle adults and larvae eat the leaves, buds and shoots of the Eucalyptus trees, which retards tree growth and contorts and eventually kills branches of trees that are heavily infested *(Tooke, 1955)*. Female snout beetles lay their hard brown egg capsules on shoots and young leaves. The egg capsules, composed mainly of faeces, contain about eight eggs. The neonate larvae emerge after 7 – 10 days and the pass through four instars. The first instars feed on the surface of the leaves, whereas the later instars consume the entire leaf blade (*Carbone et al., 2006*).

One of its natural enemies is the parasitoid *Anaphes nitens*, it is an egg parasitoid, which has been introduced into many countries as a biological pest control, there is important necessity of biological control with it, because there exist many affected areas by Eucalyptus snout beetle without any improve of that situation, or control by insecticides as ingestion of lufenuron, flufenoxuron, lambda (λ)-cyhalothrin, cypermethrin, thiamethoxam and five entomopathogenic insecticides (*Molina and Carbone, 2010*). Therefore is becoming to be more popular plant *Eucalyptus nitens*, which is resistant from the efect of *Gonipterus scutellatus* (Chapter 3.6).

3.6 ***Eucalyptus nitens***

There is a high increase of *Eucalyptus nitens* plantations based on the policy of ENCE company, many privat land owners are just following its decision and replanting existing *Eucalyptus globulus*, looking forward for higher profit. This success of the species is due to the number of advantages it presents, such as its high energy potential (*Pérez et al., 2006*), its good resistance to fungus and insects such as *Gonipterus scutellatus* and its tolerance of low temperatures (*FAO, 1981*). *Eucalyptus nitens* is one of the most promising hardwoods for plantations in cool temperate regions of the world (*Muñoz et al., 2005*). All this facts allow to spread this extensive cultivations at the areas with higher alttitude and lower temperatures without any negative affect of *Gonipterus scutellatus*, both of those facts were limiting factors for actual *E. globulus* trees. The first *Eucalyptus nitens* plantations in the northwest of Spain were established in the early 20th century, principally for pulp production. Even though early studies on the potential use of residual biomass from forest activities, i.e.

thinnings and clearcuttings, suggested that it would be insufficient to cover future demand for bioenergy (*Pérez et al., 2006*), the huge increase in the land area planted with this species in the northwest of Spain in the last decade suggests that this situation has most likely changed.

3.7 **Socio-economic sphere**

As a result of increasing urban and industrial development during the mid-19th century, traditional agricultural and forestry activities were no longer economically viable for many rural communities, and active population largely shifted to urban agglomerations. The gradual disappearance of the rural heritage has resulted in a reduction of agricultural practices and in landscape scale land retirement modelled only by aging residents (*Pérez and Vicente, 2008*). In view of the significant detriment to the land and to socioeconomic conditions, forestry began to be regarded as a new chance to recover and renew rural areas. Thus, particularly from the middle 20th century, a number of policy tools, such as grants, premiums and subsidies have been developed and launched to make afforestation programmes socially attractive (*Clinch, 2000*). Degree of public intervention in forestlands between 1941 and 2000 might have been one of the key factors in the decline in the number of farm holdings during the 1962 – 1999 period and in population changes between 1960 and 2001, at the municipal level. The rural population was led to individually parcel out and intensively manage their own farmlands and the remaining non-afforested communal lands in order to compete or survive within a market economy. The most relevant pattern of land use change was observed during the 1940's. On 10th of March 1941, the national Government took over the role of land investor by enacting by the Spanish National Forest Estate Act (NFE), in an attempt to tackle the problem of the low production, scarce profitability and deforestation of state woodlands. The NFE policy had three main objectives: land protection, especially watersheds and torrential rivers, intensive timber production, and reduction of unemployment among workers and farmers (*Pérez and Gueimonde, 1996*).

In general, such forestry measures have been based on scarce and non-transparent public information and participation, moving away from real needs, requirements and land management system of the rural population and triggering a lack of general support forest policies among target landowners. Nowadays, public administration must share responsibilities with local population in order to propose and implement successful forestry measures in land planning, especially in areas lacking a clear pattern of forest use and management. The Public Administration should particularly encourage models of land allocation and planning, such that the rural population could take over the role of land investors more easily and could design and choose a model of forest use and management that is balanced with their land demands (*Pérez and Vicente, 2008*).

3.8 **ENCE - cellulose and energy leading company**

In 1957 the Spanish National Institute of Industry created the National Cellulose Companies called ENCE (*Ruiz and López, 2010*), already mentioned name in the text above. Ence is a world leader in eucalyptus pulp production and biomass energy and it is main pulp leading company for whole Galician region with international timber distribution. It has two pulp production factories in Spain, one is situated in Galicia in the city Pontevedra and the other in Asturias in the city Navia. Pulp production capacity of Pontevedra factory is 440 000 tons per year by totally chlorine free process and 520 000 tons per year by elemental chlorine free process in Navia. Ence exports about 85 % of its pulp production, mainly to Europe where it is the second company by sales, is the largest producer of energy from biomass in Spain with a generating capacity of 222,5 MW. ENCE was managing about 15 610 hectares of land and owned 2 921 hectares in Galicia in the year 2014 *(ENCE, 2016).*

4 Characteristisc of Galicia

Galicia is an autonomous community of Spain and historic nationality under Spanish law. Located in the North-West of the Iberian Peninsula (Figure 3), it comprises the provinces of A Coruña, Lugo, Ourense and Pontevedra, being bordered by Portugal to the south, the Spanish autonomous communities of Castile and León and Asturias to the east, and the Atlantic Ocean to the west and the north. It had a population of 2 765 940 in 2013 and has a total area of 29 574 km^2 (*IGE, 2016*).

Figure 3. *Localization of Galicia region on the north-west of Spain, total area is 29 574 km² (ArcGIS, 2015).*

E. globulus trees are mainly concentrated along the coastal area of Galicia, province of Ourence has only few hectars of Eucalyptus plantations (Figure 4). Data from the Fourth Spanish National Forest Inventory indicates that from whole forested area in Galicia, which is 2 030 681 ha (Table 1), takes 248 169 hectares *E. globulus* stands *(MMAMRM, 2011)*. A comparative analysis of the Second (1986 – 1996) and Third National Forest Inventories (1997 – 2007) shows that the volume of growing stock in Galicia has increased from 90 396 million m^3 of timber to 133 090 million m^3. As a result, the volume of Eucalyptus has increased by 122 % *(Gómez et al., 2011)*. Approximately half of the spanish timber supply is generated in Galicia, although this region only covers approximately 7,5 % of the total spanish forest area.

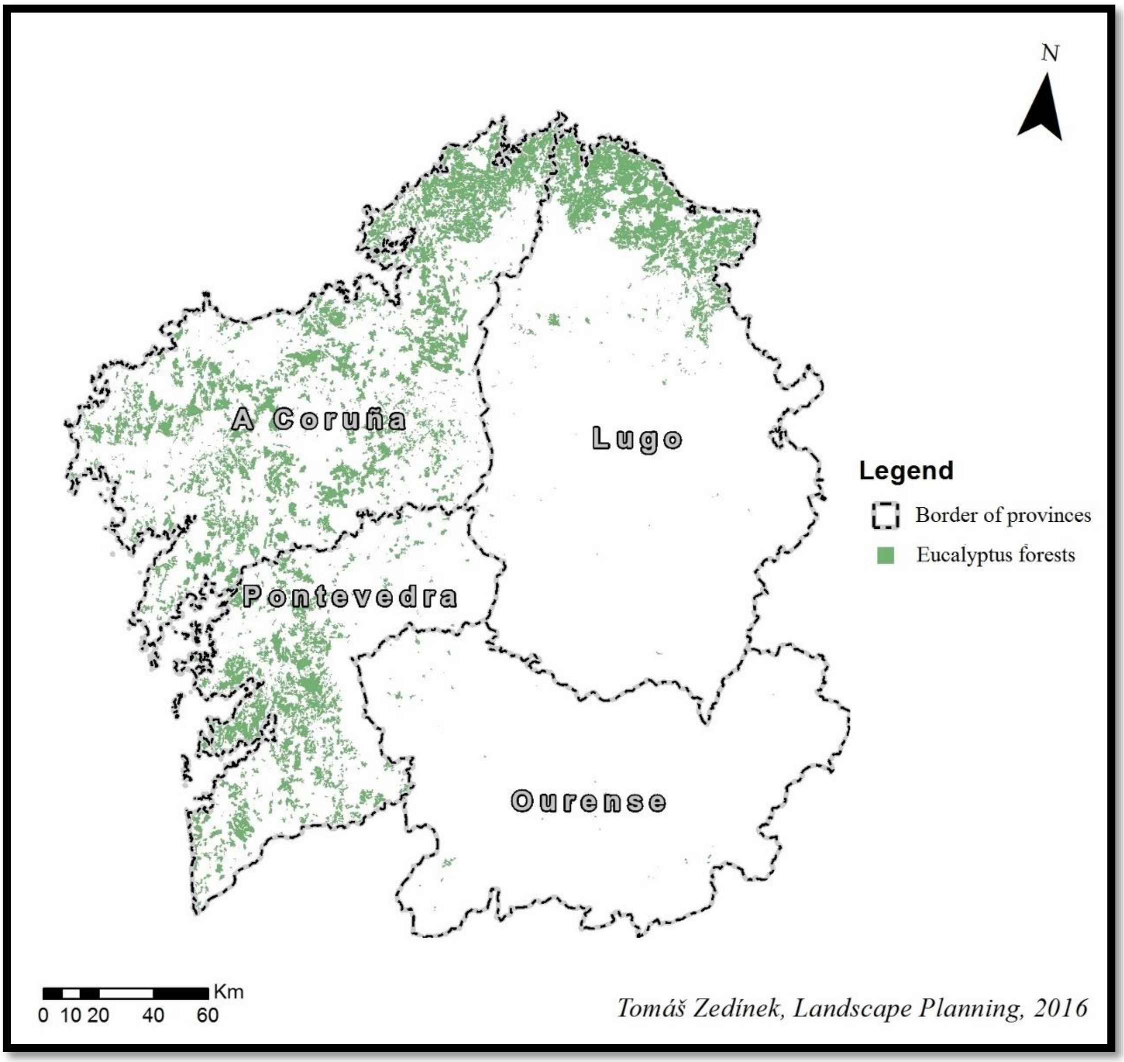

Figure 4. *Situation of Eucalyptus forests in Galicia, divided by provinces (ArcGIS, 2016).*

Province	A Coruña	Lugo	Ourense	Pontevedra
Forests [ha]	501 587	656 842	575 264	296 988
Eucalyptus trees [ha]	144 522	61 821	-	41 826
% of Eucalypt	28,81	9,41	-	14,08

Table 1. *Forested area and part of the Eucalyptus trees in Galicia (MMAMRM, 2011).*

4.1 **Lithology**

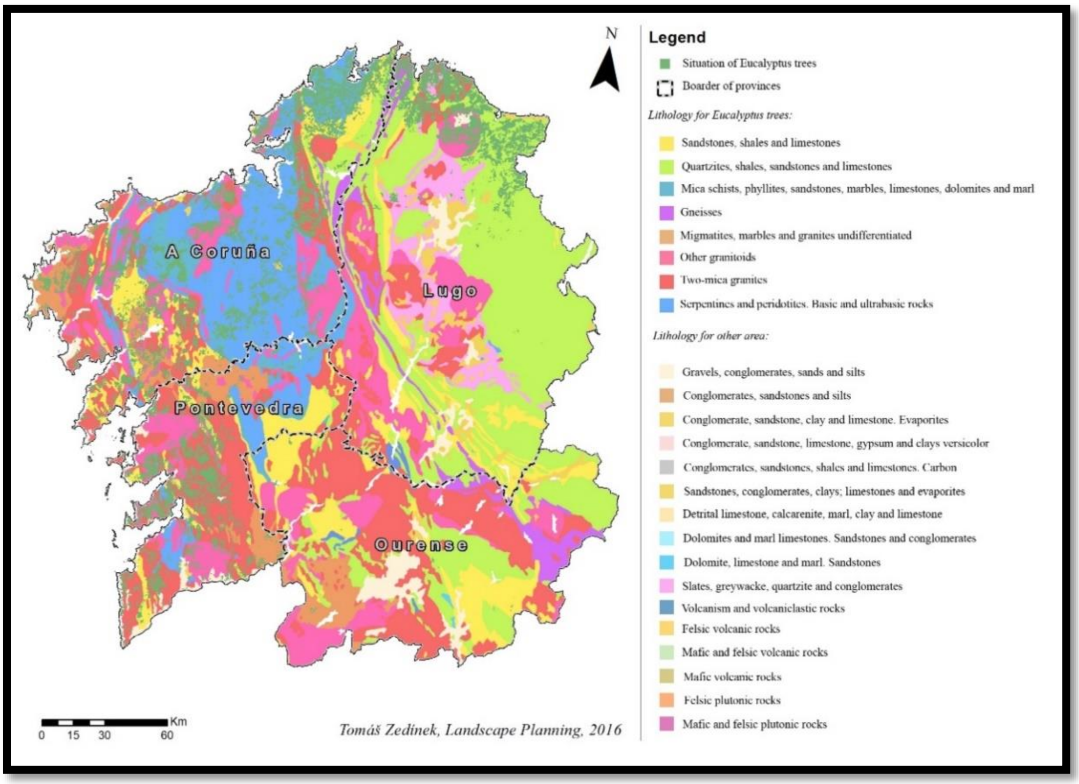

Figure 5. *Lithology map of Galicia, where you can see dominant sedimentary rocks for Eucalyptus trees also explained in Table 2 below (IGME, 2016).*

From a geological standpoint, coast of Galicia can be divided in two main blocks: granitic rocks, which occupy around 38 % of the area; and metamorphic rocks (mainly shales, schist and gneisses), which occupy 54 % of the total area. Both groups of rocks have traditionally been considered to be impervious or to have very low permeability. However, they are frequently very fractured and weathered and possess a vast network of faults and fractures (*Raposo et al., 2013*).

Province	A Coruña	Lugo	Ourense	Pontevedra
Other granitoids	Yes	Yes	-	Yes
Two-mica granites	Yes	Yes	-	Yes
Serpentines and peridotites. Basic and ultrabasic rocks	Yes	No	-	Yes
Gneisses	No	Yes	-	No
Mica schists, phyllites, sandstones, marbles, limestones, dolomites and marl	Yes	No	-	No
Migmatites, marbles and granites undifferentiated	Yes	No	-	No
Quartzites, shales, sandstones and limestones	No	Yes	-	No
Sandstones, shales and limestones	Yes	No	-	No

Table 2. *Dominant sedimentary rocks divided by provinces, mentioned in the map Figure 5 above (IGME, 2016).*

4.2 **Soils**

There are two kind of soils in Galicia region, first and the main one is humic Cambisol with edaphological nomenclature: Bh25-2bc, which covers about 36 006 km^2 and the second is generic Ranker with edaphological nomenclature: U4-2bc, which covers about 12 896 km^2. Mean that Eucalyptus trees are situated mainly on the humic Cambisol soils, which covers most of the coastal zone in all the provinces (Figure 6). Edaphological nomenclature and classification follows the rules established by the Food and Agriculture Organization *(FAO, 2016)*.

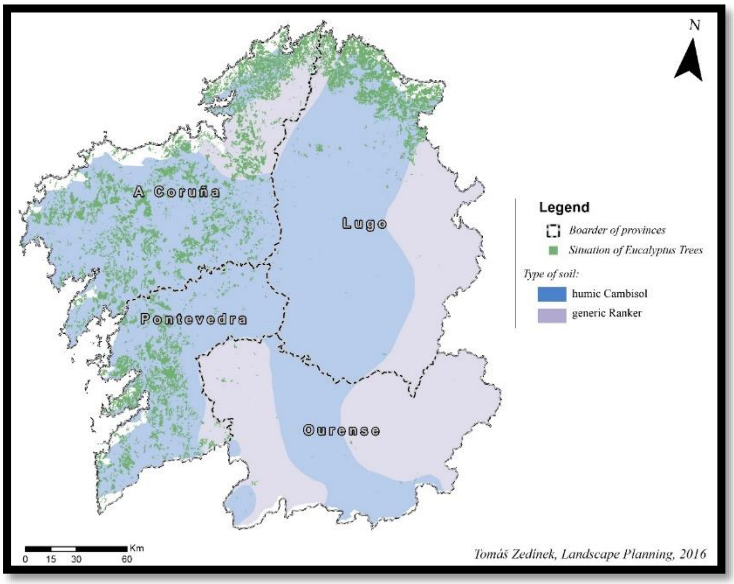

Figure 6. *Soil map of Galicia with layer of Eucalyptus trees (FAO, 2016).*

4.3 **Relief and its interactions with the atmosphere**

When we talk about the weather conditions in Galicia, we can not think only about aspects related to the dynamic of atmosphere. It is necessary to take into account other factors, because there is many set of land forms, which are making actual relief. There are two main characteristics that define clearly the relief of Galicia, first is the graduation from the coast line to the interior and the existence of a clear dichotomy (horizontal; vertical) throughout whole territory. The Galician relief is an authentic "puzzle" of "keys", which occur between the coast and the border with Asturias on the north-east, León on the east, Zamora on the east-south and Portugal on the south. Along the coast appear different dominant forms of landscape with altitude from about 30 metres to 600 meters.

The coast of Galicia has notable geographical peculiarities, opened into the ocean and very jagged bays in estuaries. Local name for this kind of inlet is Ría, its origin is from here. More to the interior, it is necessary to understand the complexity of the climate in Galicia and another key piece is the orientation, which could be also better understandable from the map of insolation (Figure 7). In general an important part is a direction from north to south. Case of the western mountain ranges is important thing that becomes a barrier that hinders the passage of the air masses from west.

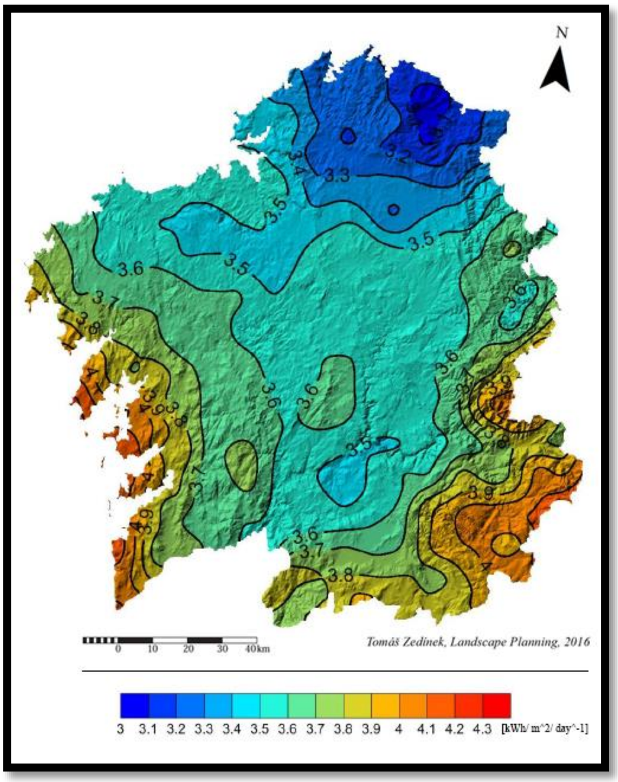

Figure 7. Map of daily global insolation for Galicia, anual average (Pettazzi and Casado, 2011).

4.4 **Precipitation**

Galicia as peninsular oceanic region is the most rainy occidental part of Europe, although the irregularity in the distribution of rainfall is a fact recurring annual level. Climatic conditions may be considered as subtropical. Abundance and spatial variability of precipitation cannot be explained basically by dynamics of atmosphere, because Galician region and its relief is very complicated, high diversity of altitude, orientation and exposition of mountains makes different precipitation conditions above whole region (Table 3). Precipitation increases generally from west to east (Figure 8). Parts of the Atlantic coast has rise the optimal rainfall gradient from 93 to 100 mm per 100 m of altitude. Annual precipitation in Galicia is 1 180 mm, while the normalized values ranging from minimum close to 500 to 600 mm in the valley of the Miño-Sil, while the values from 1 800 to 2 000 mm are measurable in the mountain range called

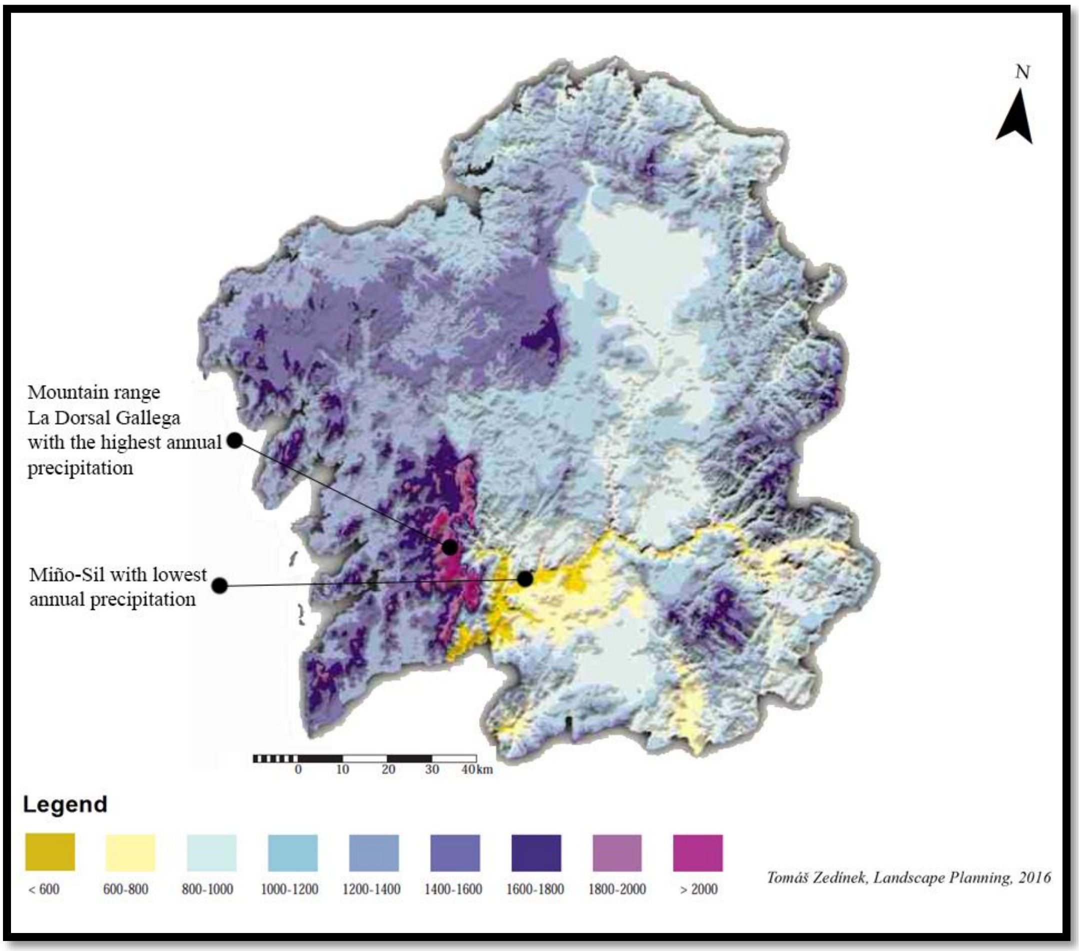

Figure 8. *Map of annual accumulated rainfall [mm] for Galicia (Cortizas and Alberti, 1999).*

La Dorsal Gallega. Total average measured in winter is 337 mm, 280 mm in spring, 156 mm in summer and in autumn 407 mm (*Cortizas and Alberti, 1999*).

Province	A Coruña	Lugo	Ourense	Pontevedra
Annual	1343	1079	994	1402
Winter	391	305	278	411
Spring	309	258	242	321
Summer	178	145	134	186
Autumn	465	371	340	487

Table 3. *Weighted average values of annual and seasonal precipitation [mm] for all Galician provinces. The coastal provinces show the values of precipitation higher than the values in the interior part of region (Cortizas and Alberti, 1999).*

4.5 **Temperature**

The weighted average of annual temperature in Galicia is 13,3° C. The weighted average of temperature in winter is 8,5° C, in the spring it is 15° C, in summer it is 19° C and in autumn it is 11° C. Therefore in the first quarter (from January to March) are recorded the lowest values of temperature for most of Galicia. The Atlantic provinces A Coruña and Pontevedra showed weighted average of temperatures higher, slightly above the 14° C and the order of 1 to 2° C higher than in Lugo and Ourense (Table 4). Over the seasons is the thermal contrast maximal in the winter with 2,7° C between the weighted averages of temperatures for Ourense and A Coruña, followed by autumn to 2,4° C and summer with 1,8° C. Spring is the season with a lower interprovincial contrast of 1,4° C with a minimum weighted average of temperature 14,2° C in Ourense and maximum 15,6° C in Pontevedra. Annual standardized temperatures ranging from values below 6° C in the Ancares mountains with south-east orientation, up to the maximum temperature of 15° C in the coastal areas at low altitude, especially in the coastal area called Rias Baixas. As can be seen in the map drawn for the average annual spatial distribution of temperature (Figure 9), it shows a variation from the coast to the interior with influence of Atlantic ocean and other north-south variation, which must be in relation with annual balance between both areas and temperate subtropical climatic effect. Overall is possible to mark a diagonal change of decreasing temperature from North-West to South-East (*Cortizas and Alberti, 1999*).

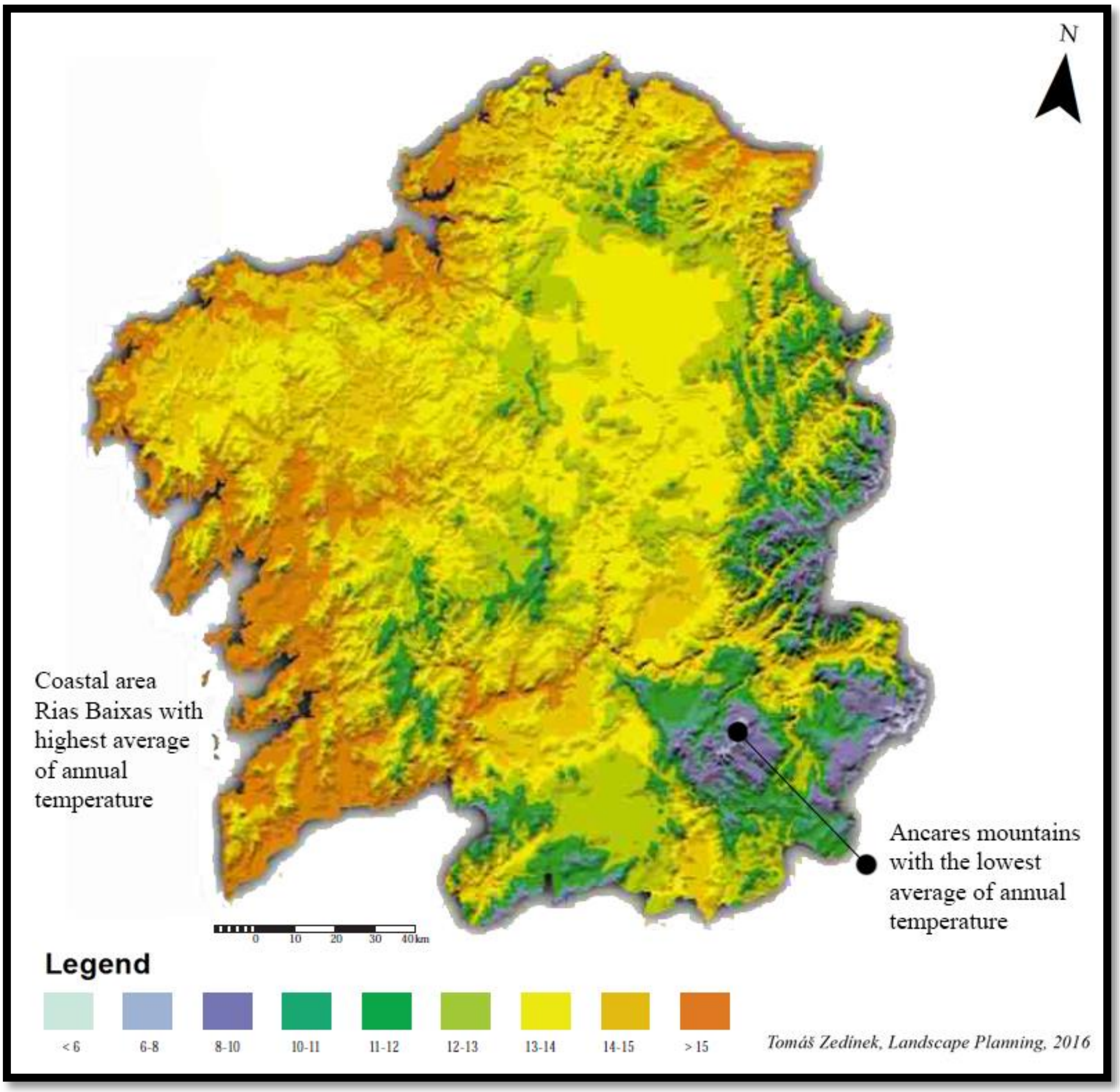

Figure 9. *Map of annual temperature [° C] for Galicia (Cortizas and Alberti, 1999).*

Province	A Coruña	Lugo	Ourense	Pontevedra
Annual	14,3	12,9	12,2	14,2
Winter	9,6	8	6,9	9,4
Spring	15,5	14,5	14,2	15,6
Summer	19,7	18,4	17,9	19,7
Autumn	12,2	10,7	9,8	12

Table 4. *Weighted average values of annual and seasonal temperatures [° C] for the provincies of Galician (Cortizas and Alberti, 1999).*

5 Methodology

Main point of this chapter is to mention main problems closely related with extensive and intensive cultivation of *E. globulus* mainly linked to Galicia, though one case study from *Zancada et al. (2003)* is situated in Asturias region, which is adjacent to Galicia from the east frontier and another one investigation of *Thomas et al. (1999)* is based in the northern part of Portugal. Localization of studies is shown in the map (Figure 10) with short description of investigation goals in the legend, sorted by numbers of studies by the order of subsections in this chapter; e.g. Example [number]. All those studies are according to mentioned problems in the introduction of thesis.

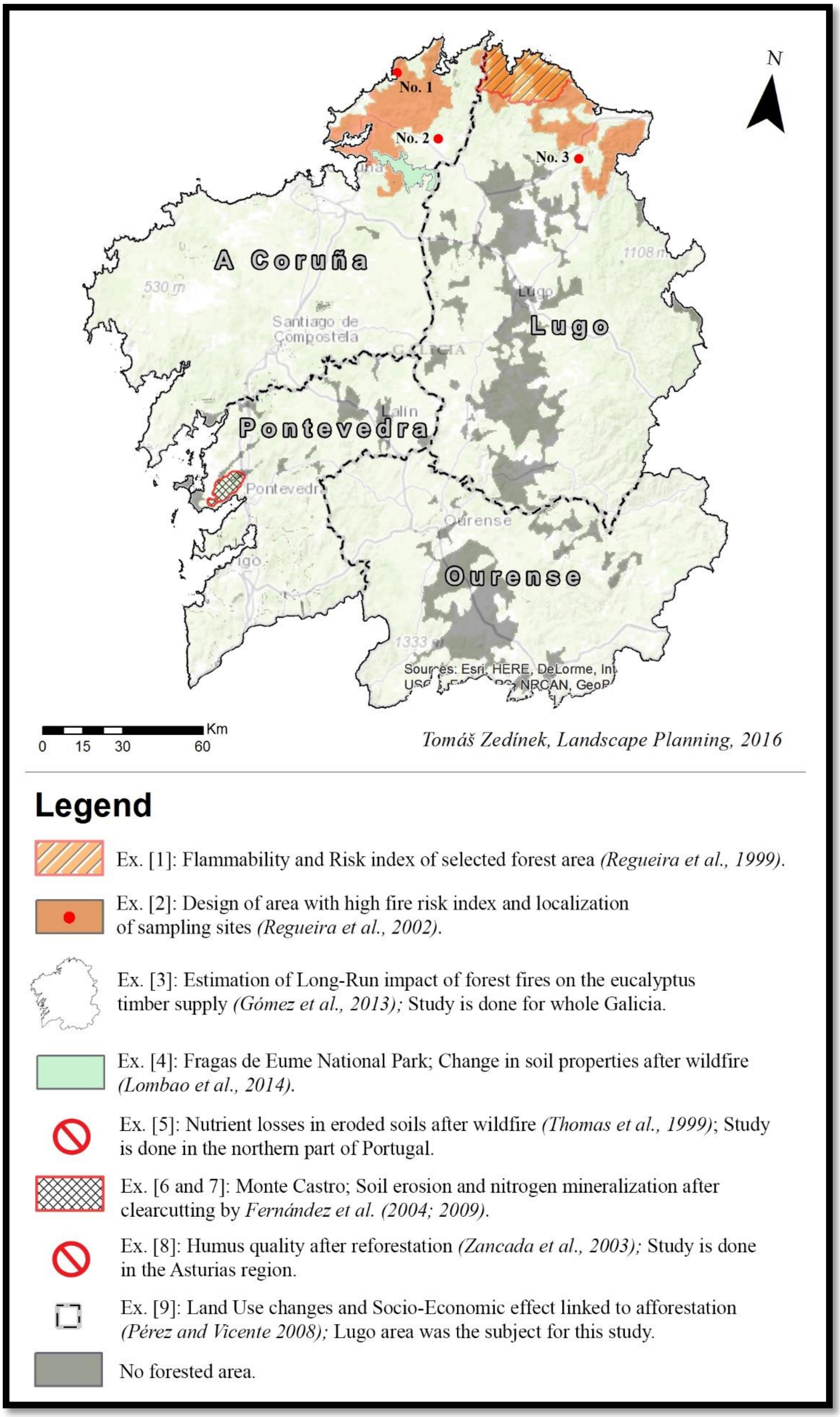

Figure 10. *Localization of studies about the main problematics related to extensive and intensive cultivation of E. globulus (ArcGIS, 2016)*

5.1 Ex. [1]: Flammability; Risk index of selected area

Regueira et al. (1999) were working on the study linked to the risk map of wildfires, they were collecting and preparing samples from one hectare of woodland in each of the study areas, which were situated in the north part of Galicia (Figure 10). Eucalyptus trees occupied about 6 % of whole surface of that area (412 500 ha), then all kinds of coniferous trees takes about 30,6 % and the last group of forest biomass in this zone is composed by bushes, which occupy 40 % of the forest surface (*Xunta de Galicia, 1992*). From every site, bulk samples consisting of bark, branches having a diameter not greater than 8 cm from pruning of trees, fruits, leaves and, in general, all of the living parts of trees were collected. Then indexes of flammability and fire risk were obtained with scale from 1 to 5, where 1 mean low and 5 high wildfire possibility (Table 5), i.e. Flammability can be considered as the ease with which a material catches fire, both spontaneously or through exposure to certain environmental conditions, or as the resistance of a forest species to starting and spreading wildfires (*Regueira et al., 2002*). High mean flammability values also mean, that these species are considered as very flammable all year round (*Regueira et al., 1999*). Risk index is based on the energy contained in the forest biomass, this is one of the main parameters used for its calculation (*Regueira et al., 2002*).

Species	**Surface [%]**	**Flammability**				**Risk index**			
		Sp.	**Su.**	**Au.**	**Wi.**	**Sp.**	**Su.**	**Au.**	**Wi.**
E. globulus	6,00	4	4	4	3	2	4	2	1
P. pinaster	12,00	4	5	4	3	2	4	2	2
***P. radiata* (Monterey pine)**	1,20	2	4	3	3	2	4	2	2
***P. sylvetris* (Scots pine)**	0,30	4	4	3	3	3	4	3	3
Conifers + hardwoods	3,00	4	5	4	3	2	4	2	2
Conifers + Eucalyptus	36,60	4	4	4	3	2	4	3	1
Others	0,90	2	3	3	2	1	1	2	1
Bushes	40,00	3	5	3	3	2	4	3	2

Table 5. *Indexes of flammability and fire risk on the north of Galicia for all seasons, it is calculated for dominant tree species (Regueira et al., 1999).*

Regueira et al. (1999) says that the final total risk index number for whole area is rounded to the next highest decimal number 3,2 and this is the value used in his prevention studies. However, using the pessimistic point of view, he says that, this number could be rounded to the next highest integer 4.

5.2 Ex. [2]: Design of area with high fire risk index

Another one study from *Regueira et al. (2002),* focused on the determination of risk indices from the biomass originating from eucalyptus residues. These samples were collected all over the year from previously chosen hectar of the forest, located in the zone of a total forest surface greater than 10 ha, sampling was done at three different locations: No. 1 in Cedeira - A Coruña, No. 2 in As Pontes - A Coruña and No. 3 in Ferreira - Lugo (Figure 10). In this zone is the predominant forest specie *E. globulus*, this was 15 years old one stand hectar forest. Samples were leaves, branches having a diameter less than 3 cm and branches with a diameter between 3 and 6 cm.

Risk index was calculated for dead matter with final value 5 and for live matter with final value 3 for existing study locations. Scale of calculated values is the same as in the study above done by *Regueira et al. (1999),* mean that value 1 is low possibility of fire risk and value 5 is the highest possibility of wildfire. Then you can see in the map (Figure 10) highlighted areas related to final risk indexes as a results of this study corresponding to August.

5.3 Ex. [3]: Estimation of fire impact on timber supply

Gómez et al. (2013) proposed and developed a three-step procedure as a guide to conduct a robust econometric analysis for estimation of long-run impact of wildfires on the eucalyptus timber supply in Galicia. In the first step, he made use of the autoregressive distributed lag bounds testing approach to check the existence of a long-run relationship between the eucalyptus timber harvest and a set of explanatory variables, such as the eucalyptus timber price, pulp exports and the eucalyptus salvage timber. The latter variable is considered a good proxy of forest fire damage. Once the existence of a long-run relationship among the variables was confirmed, the following step was to estimate the eucalyptus timber supply using the error correction model and assuming a general-to-specific approach. Finally, in the third step, he calculated the long-run impact of the explanatory variables on the timber supply and also estimated the confidence intervals associated with each impact.

Observation and its results led to the conclusion, that forest fires have not caused supply shortages. The forest fires seem not to represent a threat for the pulp industry because there is no undersupply of eucalyptus timber in the market that pushes the price to be higher. Therefore, the conclusions suggest that there is no need to subsidize the plantation of eucalyptus to ensure the supply of raw material to the pulp industry. First, the volume of growing stock has increased significantly in the recent decades and even in the periods of high damage caused by forest fires. Second, timber harvested has not decreased. This finding is certainly in line with the widespread opinion of the vast expansion of eucalyptus *(Amil, 2007a)* and the results of the second and third National Forest Inventory. In these circumstances the continuous high annual number of forest fires has not increased the scarcity of eucalyptus timber. On the contrary, the volume of damaged timber has slightly increased the eucalyptus timber supply.

5.4 **Ex. [4]: Change in soil properties after wildfire**

Lombao et al. (2014) did a study performed in one of the six natural parks in Galicia, called Fragas do Eume (Figure 10). Vegetation is dominated by “Fragas” natural woodland with a mixture of species. However, the protected area also included vegetation dominated by non-autochthonous species such as *E. globulus* and lesser extent *Pinus radiata* (Monterey pine). On March 2012 a wildfire destroyed for three days the heart of the park and approximately 1000 ha were affected, 750 ha dominated by non-autochthonous vegetation, mainly *E. globulus*, and 350 ha dominated by climax vegetation, mainly *Quercus robur* (English oak). The extent of fire can be partly explained by the different susceptibilities of the two tree species to combustion.

The level of combustion of the organic layer and the deposition of ash from the aboveground combustion of the biomass suggested that fire severity had been moderate to high *(Vega et al., 2013)*.

In order to evaluate the impact of this wildfire, were chosen plots with different species compositions named according to the dominat species (*Quercus*, climax vegetation; *Eucalyptus*, non-autochthonous vegetation) both in the unburnt and burnt areas were selected at different locations throughout the park. Thus, a total of 16 plots, each plot covering a surface area of about 1000 m^2, were established for the field experimental design. The following soil properties were monitored in the < 2 mm fraction. The methods described by *Guitián and Carballas (1976)* were utilized to determine the following physical and chemical properties. The microbial biomass was determined using the fumigation extraction method with some modifications *(Raviña et al., 1992)*. The soil respiration, an overall index of activity of heterotrophic microorganisms, and the measurement of three specific enzyme activities were used as indicators of soil microbial activity.

Overall quality of the soils of the Fragas do Eume Natural Park following a wildfire was evaluated by multivariate statistical techniques in two ways, using either physicochemical, chemical and biochemical properties or analysis of the phospholipid fatty acids. Results were observed independently of the multivariate soil status assessment indicating that the quality of the soils is mainly determined by vegetation and only to a lesser extent by soil depth and burning. Soils under Quercus exhibited a higher quality and different microbial community composition than those under Eucalyptus. Most selected soil physicochemical, chemical and biochemical properties have experienced short-term modifications following wildfire; however, the magnitude of these changes and/or high spatial variability among the field plot replicates, makes it difficult to detect significant changes. The importance of a fire as a disturbance agent in these forest ecosystems and the relevance of the vegetation in determining the soil quality are demonstrated.

5.5 **Ex. [5]: Nutrient losses in eroded soils after wildfire**

Thomas et al. (1999) did a research about the nutritient losses in the eroded sediment after the wildfire in northern Portugal. They did a comparation between burnet and unburnet plots. The tree species in the planted forests of the region are mainly *E. globulus* and *P. pinaster* with some *Acacia longiflora* (Long-leaved wattle) and *Acacia dealbata* (Silver wattle). Four main study sites were established in autumn 1992 in burnt forest stands of *E. globulus*; burnt on July 1992 and in adjacent unburned forest locations of eucalyptus. Slope angles and pre-burn forest characteristics were similar in the burnt and unburned sites. At all sites the soils are of sandy loam to loamy sand texture. Soil nutrient concentrations are similar at the burnt and unburnt eucalyptus sites. However, at the burnt sites, N, P and K are concentrated in the ash and upper mineral soil layers. Sediment and nutrient losses at each site were assessed using bounded plots, constructed using brass strip to form raised edges. Each plot was linked to a sediment trap, a tipping-bucket and two collecting tanks. The sediment traps were designed to collect only material transported from the plots and prevented influx of wind-blown material and coarse litter debris. Soil samples from both burnt and unburnt sites were taken in September 1992, April 1993 and November 1993.

Results of their study says that the concentrations of all nutrients measured in the eroded material from both burnt sites were considerably higher than mean concentrations in the surface soil. N losses were largest followed by much smaller losses of exchangeable K and available P. However, losses of available P at both sites constituted the biggest proportion of soil nutrients and are likely to have the greatest adverse affect on soil fertility. The nutrient losses suggest that recovery to pre-fire nutrient levels would take up to five years, depending on the rate of revegetation.

5.6 **Ex. [6, 7]: Soil erosion and nitrogen mineralization after clearcutting**

Fernández et al. (2004) and *Fernández et al. (2009)* did a studies at the same place and in the same conditions. First study was related to the assessment of soil erosion after the clearcutting of *E. globulus* trees by different residue managements, and the second study was about the nitrogen mineralization in the soils, after the same experiment. So, both of the studies were carried out at Castrove Mountains (Figure 10), near the ocean inlet of Pontevedra. A recently harvested area in a second growth of *E. globulus* stand on a relatively homogeneous slope of 50 % was selected in the spring of 1994. Stand age was 15 years with a density of 1100 trees / ha. The understory was dominated by *Erica cinerea* (Bell heather), *Calluna vulgaris* (Common heather) and *Ulex europaeus* (Common gorse) plants (Table 6 in Chapter 7.2). The treatments were: clearcutting + slash scattering; clearcutting + slash scattering + fertilization (100 kg / ha of which 15 kg of nitrogen - N, 15 kg of phosporus – P and 15 kg of potassium - K); clearcutting + windrowing; clearcutting + slash scattering + burning (broadcast burning) and clearcutting + windrowing + burning (windrow burning).

Their results related to soil erosion said that there wasn‘t detected erosion threat throughout the study period in undisturbed *E. globulus* stands, suggesting that an effective erosion control takes place in these intensively treated plantations! Soil erosion after harvesting and slash disposal treatments was relatively small for all the techniques employed. Nevertheless, slash scattering and windrowing brought out comparatively less soil losses than burning techniques. Consequently, if *E. globulus* slash burning needs to be prescribed to reduce fire hazard, it must be conducted with high soil moisture content just before burning and avoiding high slash accumulation to effectively control soil losses *(*Fernández et al. 2004*)*.

Results about the nitrogen mineralization said, that harvesting and more conservative slash treatments (scattering and windrowing) surprisingly did not result in significant changes in mineral N. This is consistent with the conservative behaviour observed in these eucalyptus stands, in which nutrient outputs in total runoff are usually lower than rainfall inputs (*Dambrine et al., 2000*), as well as with the absence of signs of N deficiency and sustained growth of these stands. The lack of response of mineral N immediately after burning was not anticipated. The reason for the delay in response is not clear, although the results strongly suggest that it was related to the greater severity of the fire. However, in the short term, increases in fire severity resulted in decreases of N mineralization and nitrification. Although windrow burning led to greater losses of N from the system than broadcast burning, paradoxically, the latter gave rise to twice the amount of mineralized nitrate than the former, with the subsequent higher risk of cation leaching in these desaturated soils. Apparently, the latter would make these intensively managed stands less sustainable, that demonstrates the complexity of the N mineralization response after fire and that additional research is required to clarify these points. Treatments such as burning, which simultaneously enhances total N losses and risk of cation leaching, obviously should be avoided in soils such as those under study *(*Fernández et al. 2009*)*.

5.7 **Ex. [8]: Humus quality after reforestation**

Zancada et al. (2003) studied with his colleagues humus quality after the reforestation of eucalyptus trees. The studied area was located in Asturias, region next to Galicia. The sites selected for its study included undisturbed soils with the potential undisturbed original vegetation, then soils under *E. globulus*, corresponding to both situations there were locations with ancient trees, 20 years old and recently reforestated places.

Their resulst showed that reforestation of eucalyptus trees led to increased organic matter accumulation in soils mainly in the ancient forest, where the soil carbon in the upper horizon was even greater than in the neighbouring location with heathers and pine trees. In the samples studied, it was evident that the introduction of the eucalypt forest has substantially modified the fungal population contributing to the accumulation of the humic acid soils. Humus composition ranged between extremely different values. Since the time elapsed after the reforestation seems to be an important source of this variability, it is also likely that because of the low degree of association between organic and mineral matter under eucalypt-reforested soils, the derived humus may be highly responsive to local abiotic factors, such as soil reaction and texture.

5.8 **Ex. [9]: Afforestation effect on Land Use and Socio-Economy**

Study of *Pérez and Vicente (2008)* aims to empirically analyze and validate the temporal and spatial changes in land uses and the socio-economic effects linked to two public schemes of field-afforestation on private lands in the province of Lugo (Figure 10). Two different spatial levels were considered: municipalities and parishes. Data were obtained from different public sources. The official data of population statistics, farm holdings, land tenure, structure, use and management. The series of public field-afforestations on private lands, were suitably homogenized, validated and stored in a Geographical Information System (GIS) in vector format at municipal and parish levels. The targeted sample was composed by 1355 farmers, who collectively managed more than 13 500 ha of farmland. All farmers were interviewed by a team of 43 interviewers who were trained in agriculture.

The results suggested that the degree of public intervention in forestlands between 1941 and 2000 might have been one of the key factors in the decline in the number of farm holdings during the 1962 – 1999 period and in population changes between 1960 and 2001, at the municipal level. At the individual farm holding level per parish, land parcelling and agricultural intensification might also explain why farmers in parishes with mixed forest management received a higher annual family income than the remaining farmers during the 1993 – 2003 period. Fast-growing forest species were the main option for individual private afforestation in parishes, where Public Administration and private landowners shared forest management, despite the major past social conflicts caused by public forest intervention. However, forest fires were particularly critical in parishes with mixed communal forests management; such parishes showed more social conflicts against public field-afforestations.

6 Current state of the problem

More than half of the total wooded-land in Galicia is covered by *E. globulus* and *P. pinaster*. Ecological terms such as „alien species“ or „pyrophytic species“, which may not be included in any official international, national or regional statistics, are used to describe the characteristics of some species. *E. globulus* actually encourages the spread of fires by copious litter production, inflammable oils, and highly flammable bark. At the same time, the presence of eucalyptus in Galicia has multiplied by six in the last 25 years as a result, in part, of the self-regeneration after wildfires. In this sense, most adult plants survive a fire and resprout from the roots or stems and also colonize adjacent lands *(Hidalgo, 2007)*. Moreover, the important presence of eucalyptus in the Galician forest has also been the result of plantations starting last century.

Indeed, the only pulp mill that was created in Galicia in 1957 (ENCE), constitutes a perfect example to identify resources and industrial development. Its location was directly related to an easy provision of pulpwood due to the already mentioned reforestation policy, specializing in coniferous mainly in the 1950‘s to gradually change in 1970‘s to eucalyptus as ENCE was modifying its productive process *(Boquete, 1999)*. Nowadays, after 60 years of ENCE presence, expired rental agreement for fabric in Pontevedra at this year. There was a huge pressure from the public, which do not agree with ENCE policy and its extensive environment consequences to do not extent existing rent of the fabric and do not allowe to continue working this monopol company anymore at this place. Let’s say, unfortunately higher interest makes the new rental agreement signed for another more 60 years. This was done by the actual government, though actual political situation is not clear in Spain after the last elections from December of last year and the opposition of winning party argue, that the signature of rental agreement as ilegal, because there is a high probability of new elections in the country; thus the sign can’t be accepted as a valid. Of course, besides the promotion by institutions, plantations with eucalyptus by forest landowners have also been influenced by the high yield of the stands with an average growth rate of 20 m^3 / ha / year. All these elements have contributed to the vast expansion of eucalyptus in Galicia. It seems clear that an additional critical aspect for the Galician forest is the dramatic decrease of pulpwood prices in the last years. This price depression has been accentuated by the monopsonic practices of the pulp industry *(Amil, 2007b).*

Main threat for Galicia and its environment is wildfire, it is dominant point for most of the studies related to *E. globulus* cultivation in Galicia and it acts in further consequences with other mentioned problems of soil quality and erosion, ecosystem stability, timber economy and social welfare. Alarming fact is that most of the fires are caused by man, arson being the most important cause, while the latter is related with the colonization of land by bush and wood fuel accumulation. In addition, the climatic conditions play an important role. Growing number of fires are set intentionally in Galicia to obtain temporary jobs with the firefighting services. Although this is not an important cause in absolute terms, it may be significant and a result of some forest fire policies. From 1985 to 2005, six fires have been officially reported to be set intentionally by firefighters in Galicia, while in 2006 these figures grew to 15 fires, with four auxiliary workers detained *(Martín et al., 2007)*. It is well known the high capacity of Galician forest to accumulate and regenerate biomass due to climatic conditions and soil characteristics, and other important social and economic factors *(Xanthopoulos et al., 2006).* Some of them are related to the abandonment of traditional agrarian practices, rural exodus and the absence of forest management in a large part of the forest land. According to estimates from the Third National Forest Inventory *(MMA, 2001; CMA, 2001)*, silvicultural practices are absent in 86 % of the wooded-land, primarily being mixed stands *(AFG, 2005).* There is a debate about fire prevention or fire suppression in terms of efficiency and cost, policies with preventive silvicultural practices (reforestation and care of existing stands, fuel management, etc.). The major problem in Galicia is the economic cost of the prevention due to the extent of the area to be treated and the small size of the plots, but important amounts of money are also needed for suppression and restoration. In addition, wildfires cause significant environmental and social costs.

7 Variants for dealing with the problem

Main focus of solutions in this chapter is concentrated to the fire prevention, because this is the begining of the chain, consequences of wildfires are related to the erosion threat, loss of biodiversity and environmental quality, therefore the economic situation and social welfare. Firstly is mentioned fire prevention in the scale of production forest (Chapters 7.1.1.1; 7.1.1.2 and 7.1.1.3) and then in the wide-scale landscape measures (Chapters 7.1.1.4 and 7.1.1.5). After we will talk about the antierosion measures by mulching (Chapter 7.1.2.1), hillslope barriers (Chapter 7.1.2.3) with seeding treatment included (Chapter 7.1.2.2). Focuse to the increasing of environmental qualities and higher biodiversity is in the Chapter 7.2, then the land management is mentioned with its optimalization (Chapter 7.3) and together with part about non-timber resources (Chapter 7.4) it should bring ideas how to refresh economic income and working possibilities in Galicia.

7.1 Fire prevention and antierosion measures

These are thought how to improve the forest management by creating strategic units with a size compatible for local sustainable objectives and actions. The management of the burned areas should consist of a range of techniques that will be carried out before (1) Ex-Ante; and after (2) Ex-Post the fire; i.e. respectively preventive and mitigating strategies. Different solutions and methodologies are applicable to different geomorphological and landscape units (*Moreira et al.*, *2008*). So, the management options to solve the problem can be synthesized at two levels *(Shakesby and Doerr, 2006).*

7.1.1 Ad. (1) Ex-Ante

Possibly during the plantation of forest stands, installation of measures and planning the activities to be carried out inside the burnt area, so that the forest fire occurrence does not degenerate into a catastrophic phenomenon. According to *Moreira et al. (2008)*, land use planning for wildfire prevention has to take into account three main aspects:

7.1.1.1 **Facilitate forest accessibility**

Locations of roads and firebreaks can be optimized to reduce the risk of fire progression. There is existing very rich road site all over the Galician landscape, which allow the owners to easily access to their private land. These roads are further dated into the past, it is important and should be own interest of all those responsible people to maintain that communication site in a proper way, not just for the access of firemen, but also as a possible barrier against the spreading of wildfire (Photo 22).

Photo 22. *Well maintaned forest way from the extensive fuel greenery along and between the forest production site (www.ief.mg.gov.br).*

7.1.1.2 **Splitting the production site in small forest units**

For to achieve more complicated mosaic of relief, which can decrease spreading of fire based on the understorey vegetation masses; e.g. could be good example of fire brake prevention, system of ditches over the land, which can still allow the owner make a maintenance by heavy machinery, but did not allow to grow the understorey vegetation exactly in the body of the ditch (Photo 23 and 24). Ditches should be wide about more than 1 m, the best way of preparation is done by plough behind the tractor and of course with all the sense to possible erosion threat at the site.

↑ ***Photo 23.*** *Preparation of ditch as a fire brake for current fire threat (www.jrts-polk.army.mil).*

← ***Photo 24.*** *Ditch as a fire brake, which did not allow to grow the understorey vegetation (Wikipedia).*

7.1.1.3 **Forest scale fuel regulation**

This part should be closely related with the proper maintenance of the road infrastructure and its cleaning along, i.e. between the communication and the production forest land. Of course, the main part is about fuel regulation inside the production site (Photo 25), common way how to prevent the land against the fire is by cleaning the surface from the unfavorable greenery, what is mainly done by mulching and cutting machines as it was mentioned (Chapter 3.2). There is an existing law of *Act No. 3 / 2007 Coll.*, about the prevention and protection against the forest fires in Galicia, which gives order to all landowners keep their land property enough maintained against the fire threat.

Photo 25. *Good example of eucalyptus production forest, within part understory is enough regulated and the outside "buffer zone" is cleaned by mulching technique.*

Those three mentioned prevention steps promoted by *Moreira et al. (2008)* above are applicable clearly for eucalyptus timber production site without any direct relation to agricultural land, or urban area. So the conclusion is to have well accessible forest site, where the communication will be maintain by cutting or mulching technique along, the same as the buffer zone around the production part. Then the specific forest land suppose to be divided by system of ditches and provided by cleaning measures over the year; e.g. mulching, or cutting prevention maintenance between the trees and between the system of ditches. At the wide-scale landscape feature, where the agricultural land and urban area are included, part of the fire prevention measures is recommended to use prescribed fire (Chapter 7.1.1.4) and wide-scale fuel regulations (Chapter 7.1.1.5).

7.1.1.4 **Prescribed fire as a firemen measure**

It is old existing fire prevention technique, which has been developed in several locations in the world, particularly using prescribed fire (*Vega et al., 2005; Pierson et al., 2009; Burrows and McCaw, 2013; Fernandes et al., 2013; Ryan et al., 2013*). Fire has been used as a management tool to control the fuel in shrubland and to control the ladder effect of shrub and herbaceous vegetation in the forest understory (Figure 11). This is a technique that can be used at the forest landscape to promote diversity and decrease the connectivity and transmission of hydrological and erosion processes between different landscape compartments.

Prescribed fires have significantly lower impacts when compared with wildfires, but some considerations need to be met: (1) it should occur out of the critical fire period, under wetter conditions and lower temperatures; (2) the fuel load available to burn must be generally low; and (3) it must always be performed in bands, first burning the top and then sequential bands towards the bottom of the slope (*Botelho et al., 1994*). Thus, prescribed fires reach temperatures significantly lower than those of wildfires.

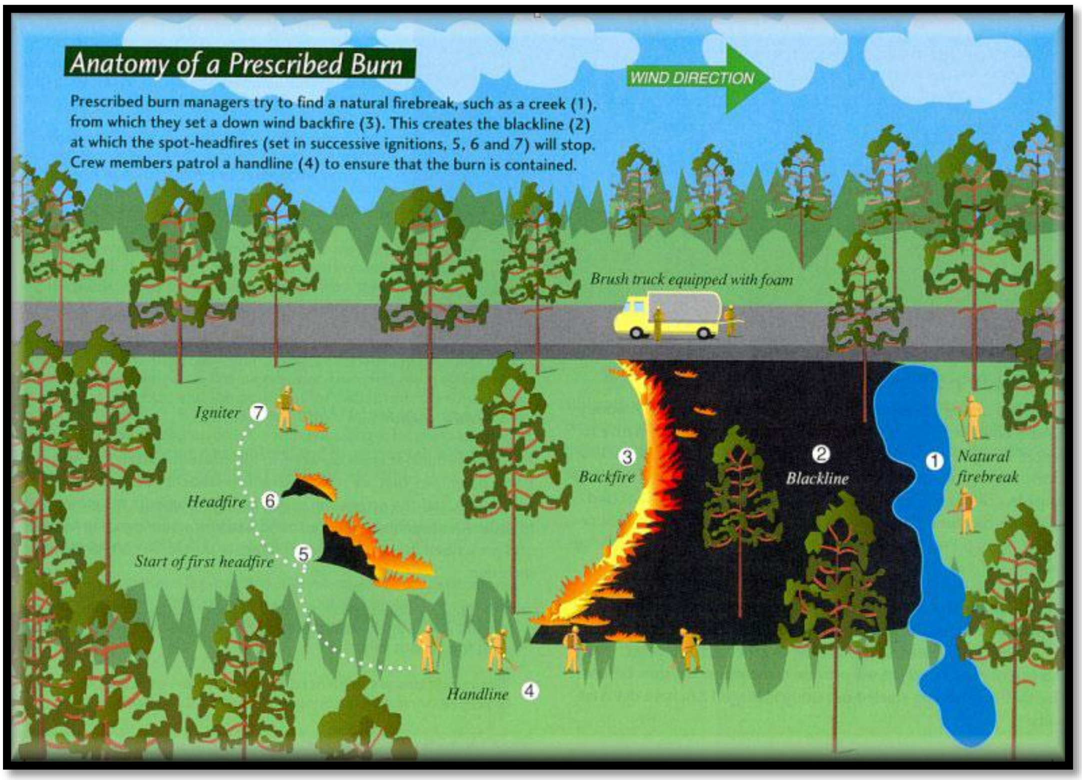

Figure 11. *Graphic description of prescribed fire management (pagamecommission.wordpress.com).*

7.1.1.5 **Wide scale application of fuel regulations**

Area-wide fuel modifications are an extensive application of fuel treatments at the forest stand level that include reduction of fuel load, increased fuel compactness and disruption of vertical and horizontal fuel continuity *(Chandler et al., 1983)*. Although it is much less strategically planned than fuel break networks, it may complement it by working inside the landscape units isolated by the fuel break

Photo 26. *Photo taken in the Mediterranean area, where the stand of C. sempervirens showed amazing fire resistance against the extensive wild fire threat (www.agenciasinc.es).*

network. The patchy pattern of fuel treatments creates a landscape mosaic that increase its resistance to fire spread by the limitation of ladder fuels *(Vélez, 1990, 2000)*. Fuel type conversion involves replacing highly flammable vegetation by low growing, less hazardous species *(Rigolot et al., 2009)*; e.g. *Cupressus sempervirens* (Mediterranean cypress) which showed amazing fire resistance and it shoud be prefered as a fire brake tree specie (Photo 26). Real fuel type conversion towards fire resistant vegetation is mostly limited to wildlande-urban interfaces where landowners can choose less flammable ornamental (preferably native) species (Chapter 7.2; Table 25). In wildland areas, natural succession can be used where site conditions enable it to promote a mixture of species and to favour mature stages *(Vélez, 1990)*. This naturally slow process can be somewhat speeded up with some selective thinning favouring broadleaved species (*Quercus robur, Q. Pyrenaica, Castanea sativa, or Betula pendula) Duché and Rigolot (2000)* distinguish three main objectives for fuel breaks: (1) to decrease fire ignition events; (2) to decrease total burned area; and (3) to decrease fire effects on people, human resources and ecosystems. Thus, fuel break design and evaluation of effectiveness will differ depending on the objectives. Clearly, the effectiveness of fuel management in general and of landscape fuel breaks in particular can not be solely assessed by fire size reduction and effective fire suppression, but it should also take into account the benefits for fire suppression actions and the reduction

Photo 27. *Example of strategic fire break between two production sites with forest road in the middle for better access for firemen in case of fire threat, in this case as in the many existing the width is less than 100 m (www.navarra.es)*

of the environmental and the socio-economical impact of wildfires. The fragmentation of a fire prone matrix with patches in different successional stages, the introduction of narrow corridors between wooded patches and the promotion of convoluted perimeters were effective in reducing fire size *(Duguy et al., 2007)*. The implementation of a fuel break network requires a fire management plan at the landscape level. Landscape fragmentation is ensured by primary and secondary fuel break networks, the former being strategically located (e.g. ridge top fuel breaks) for increasing the efficiency of fire suppression actions, and the latter for guaranteeing the safe accessibility to the former. Following European standards, strategic fuel break (Photo 27) width should be not less than 100 m *(RCC, 2002)*.

Nevertheless, the main preventive strategies to reduce fire incidence and its deleterious effects will be to promote land use diversity, building a landscape mosaic that can reduce the area burned in case of fire outbreak (*Ferreira et al., 2010*).

7.1.2 Ad. (2) Ex-Post

Immediately after the fire, implementation of measures to reduce the soil erosion caused by transmission of water. Despite the urgency and relevance of studying and developing strategies to reduce soil degradation after forest fires, the solutions must be evaluated on a cost/benefit basis (*MacDonald and Larsen, 2009*). This implies that to be feasible, any solution should be applicable to key locations specifically selected to allow the greatest possible impact in terms of conservation at the lowest possible cost (*Fox et al., 2006; Prats et al., 2014a*). The pace at which the degradation takes place after the fire (*Ferreira, 1996; Ferreira et al., 2005a*), limits the options available to mitigate the degradation processes, namely those resulting from an increase in runoff, erosion rates and dissolved nutrients exported shortly after the fire. *Ferreira et al. (2005a)* found that most of the losses occur in the first months after the fire. The quantities of nutrients lost in eroded sediment increased greatly after the fire. This was a result of the large quantities of nutrient-rich ash and partially combusted organic material on the ground surface and their vulnerability to splash and entrainment by overland flow because of the lack of a protective litter and vegetation cover. In unburnt forests, efficient nutrient cycling, minimal overland flow and the ineffectiveness of erosion processes minimise nutrient loss. Fire disrupts these processes and nutrients previously bound up in vegetation are transformed into soluble forms in ash *(O'Connell et al., 2004).*

7.1.2.1 **Mulching**

The main aim is to increase the soil cover to reduce the impact of raindrops and subsequent erosion *(Robichaud and Brown, 2005)*. Exist studies about the mulching for reducing post-fire soil erosion in different varietes, i.e. mulching with respect to: (1) straw; (2) chopped bark; (3) hydromulch; and only rarely with regard to forest residues. The selection of the material has to be done accordingly to the local availability and the price of the materials, to make this type of operation socially and economically feasible.

Photo 28. *Manual application of chopped bark and forest residue mulch with detail of its result on the surface (Ferreira, 2014).*

Photo 29. *Aerial application of straw mulch at the burned forest area (aerotechteam.com).*

The advantage of mulching is that it affects the ground cover, which was widely found to be the mean factor controlling soil erosion *(Larsen et al., 2009; Prats et al., 2012)*. Following *Prats et al. (2014a)*, mulching can reduce runoff volumes in 50 % and soil erosion in 90 %, if the application coverage reaches the threshold of 70 % of ground cover. Mulching has been typically applied manually on the soil surface (Photo 28), but aerial applications (Photo 29) can be more economic *(Wagenbrenner et al., 2006; Robichaud et al., 2013b)*.

Mulching can occur naturally (Photo 30) if the wildfire severity is moderate or low and the leaves remaining on the trees after the fire fall on the soil surface providing a natural protection against rainfall erosivity *(Shakesby et al., 1996; Robichaud et al., 2000; Prats et al., 2012)*. Needles and leaves provide protection against the movement of particles by overland flow. These authors recommend waiting for the leaves or needles to fall before cutting the burned trees *(Ferreira et al., 2014)*.

Photo 30. *Natural mulch, mainly based on fallen leaves (Ferreira, 2014).*

Another option instead of the widespread application can be preparation of mulch stripes. Thus can be set over the soil to form bands or cord barriers. Successions of mulch bands can be placed a few metres apart on the slopes so as to reduce the amount of mulch material to be applied. However, a lower application rate can compromise the effectiveness of the treatment, once that there is a lack of information about the exact space between bands, the exact applications inside each band and under which circumstances these mulch bands are the best cost-effective technique. The bands or cords of mulch can be composed of straw, forest residues, trunks and branches, burned or not, and should be grouped in cords perpendicular to the steepest slope angles, in regular and parallel bands *(Ferreira et al., 2005).*

Ad. (1) Straw is the lighter and most effective mulch material, but it is not always available in all the regions. The latest research in the USA indicated that straw is highly effective *(Robichaud et al., 2013a,c)* it has high decomposition rate (Photo 31).

Photo 31. *Straw mulch applied on the surface of burned forest area (www.sacbee.com)*

Ad. (2) Chopped bark and wooden fibres (Photo 32) of the forest residue mulch *(Prats et al., 2012, 2014a,b)* increased soil surface cover and roughness, and therefore the retention of sediments *(Shakesby et al., 1996)*, which maintained soil moisture and reduced evaporation, increased the soil organic matter content and improved the soil structure. Forest residue mulch can vary considerably, depending on the available materials used.

Photo 32. *Chopped bark fibres prepared for surface application as a antierosion measure (www.southcountycockery.net).*

There is a study of *Prats et al. (2012)* for the treatment of the eucalypt plots. Chopped bark mulch (Photo 33) was obtained, where eucalypt logs are debarked before their transport to a paper pulp factory and the bark is chopped into 10 – 15 cm wide 2 – 5 cm long fibers

Photo 33. *Chopped bark mulch applied as a antiersoin measure (www.george-walker.co.uk).*

before their transport to a biomass energy plant. Mulching with eucalypt chopped bark was, highly effective at the eucalypt site with an increase in litter cover from 10 to 70 % resulting in a decrease in 45 % of runoff amount and in 85 % of sediment losses.

Ad. (3) Hydromulch, which besides the water consists mixture of straw, shredded bark, recycled paper or any other organic material together with a colourant, a bio-stimulant, seeds, tackifiers, surfactants or other elements. The ultimate goal is to provide a layer that protects the soil against the rainfall until the germination and fixation of seeds *(Rey, 2003)*. In fact, the selection of components was found to be crucial to achieve the treatment goal *(Robichaud et al., 2013b)*. The hydromulch material is expelled by a sprinkler hose mounted in a truck equipped with a water tank and a pump, which increases the costs of this treatment (Photo 34). Alternatively, *Hubbert et al. (2012)* and *Robichaud et al. (2013b)* tested aerial hydromulch (Photo 35), but results were far from being as effective as the straw mulch. *Prats et al. (2014c)* achieved good results, probably due to the even ground application from a hose operated on foot but also to the specific hydromulch composition, included also shrub seeds such as *Cytisus striatus* (Hairy-fruited broom) and *Ulex minor* (Dwarf Gorse); mentioned (Table 6).

Photo 34. *Manual application of hydromulch at the controled area (Ferreira, 2014).*

Photo 35. *Aerial application of hydromulch at the burned forest area (Ferreira, 2014).*

7.1.2.2 **Post-Fire Seeding**

Post-fire seeding can be defined as the planting and establishment of quick growing vegetation species in order to provide ground cover to the soil until native vegetation get recovered. *Robichaud et al. (2006)* demonstrated that seeding success depended highly on rainfall intensity, amount and timing (Photo 36).

Photo 36. *Post fire area with grass seeding application after one year from the fire (USGS, 2004).*

There are different techniques of post-fire seeding: (1) direct manual seeding *(Pinaya et al., 2000; Robichaud et al., 2006)*; (2) seeding in the mulch *(Bautista et al., 1996; Badía and Marti, 2000)*, or alternatively mentioned hydromulch technique; and (3) seed-coated seeding *(Madsen et al., 2012)*. Right after the fire it is difficult for any perennial herb or any other plant that just germinate to develop their root system through the soil's compact hydrophobic layer. In the seed-coated technique, the seeds incorporated surfactants that should be released with the first rains and allow the growing of the plant in small hydrophilic channels around the seed. Nevertheless, using seeds solely, not accompanied by other techniques, is often ineffective. This is mostly because, given the speed at which degradation processes occur shortly after the fire, the seeds remaining in the ash layer are washed downstream before they can germinate, providing an effective ground cover and finally, play a significant role in soil conservation. Hydromulching (Chapter 7.1.2.1) is prefered for those negative conditions, if it allows us our financial situation.

Ad. (1) Direct manual seeding consists of handing out the seeds directly on the soil surface. It should be simple, cheap and a very suitable technique to use, especially in rough terrain. However, it is time consuming and the uneven spread may be high. For those reasons, seeding is typically applied with mulch.

Ad. (2) Seeding with mulch as a medium should increas the success of germination, because it increase infiltration and soil moisture *(Robichaud et al., 2000)*. The protection provided by mulch against the impact of raindrops, improves germination too *(Albaladejo et al., 2000)*. Mulch works also for stabilization of seeds on the steep slopes, then depends of the mix of mulch materials, but leaching of nutritions is another positive attribute. This technique is very close to hydromulching, which is mentioned above (Chapter 7.1.2.1). Way of seed application could be adaptated to the financial and environmental possibilities.

Ad. (3) Seeding of coated seeds, i.e. seed coating method allow the chemicals to be applied in a synthetic polymer that is sprayed onto the seeds and provide a solid, thin coat covering them. The advantage of the polymers is that they adhere tightly to the seed and prevent loss of active materials like fungicides, nutrients, colorants or plant hormones. They can confer temperature-sensitive water permeability to seeds or affect gaseous exchange. By this they control the timing of seed germination and seedling emergence. Certain temperature-dependent water-resistant polymers can delay imbibition until the climatic conditions become suitable for continued seedling growth *(TSBP, 2012)*. All this facts are increasing the

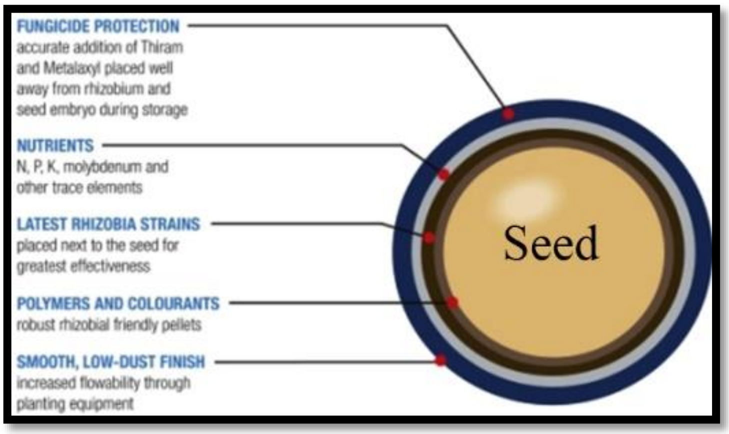

Figure 12. *Example of coated seed technology, made by Agristrike (Seedmark, 2016).*

success of seeding, different trademakrs are presenting own technologies and combination of layers for increasing the seeding success (Figure 12).

The most commonly used seeds include herbaceous seeds such as ryegrass and other leguminous commercial seed mixtures; such as *Triticum aestivum* (Common wheat), *Lolium multiflorum* (Italian ryegrass), *Lolium perene* (English ryegrass), *Agrostis capillaris* (Common bent), *Lotus corniculatus* (Common bird's foot trefoil). The most recommended seeds for seeding are mentioned (Table 6) for the environment of Galicia with high average of germination and resprouting properties after the fire (Chapter 7.2).

Morgan et al. (2014) did a comparation between rehabilitaion treatments by: (a) Straw mulch without seeds; (b) Chopped wood mulch without seeds; (c) Manual grass seeding without mulch; and (d) Hydromulch with content of grass seeds. Then you can see the contrast of vegetation understorey cover responding to three years since the fire threat occur (Photo 37). It is a great comparation of mentioned practices with much higher rehabilitation success in both treatments with seeds included (c and d), than in cases of simple mulching treats (a and b).

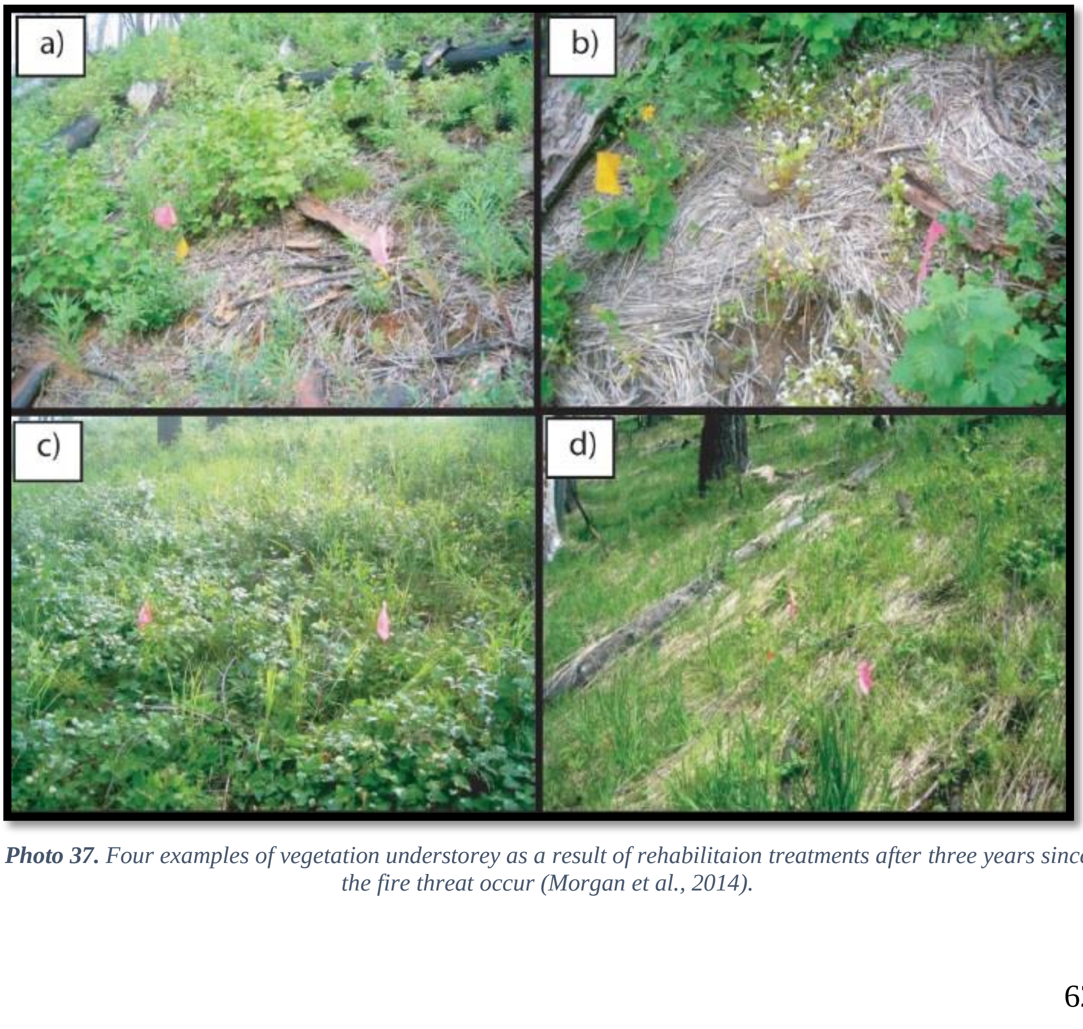

Photo 37. *Four examples of vegetation understorey as a result of rehabilitaion treatments after three years since the fire threat occur (Morgan et al., 2014).*

7.1.2.3 **Hillslope Barriers**

Recommended are: (1) log erosion barriers; (2) nylon tubes filled in with vegetation debris or for the same concept straw wattle structures have been used to reduce overland flow, promote water infiltration and trap sediments, thereby reducing the movement of sediments downslope in burned areas *(Wohlgemuth et al., 2001, 2011; Robichaud, 2005; Robichaud et al., 2008a; Fernández et al., 2011)*. Barriers are typically applied perpendicular to the overland flow processes. The contact of the barriers with the soil surface plays an important role in the capacity to trap and the volume of sediments stored.

Ad. (1) Log erosion barriers and its main purpose is to create small mechanical brake at slope scale, where the flow of water and sediments can be trapped and to promote infiltration to reduce sediment transport capacity *(Robichaud and Brown, 2005)*. The installation consists of felling down burned tree trunks, putting them in contact with the soil along the slope contour. The logs are then fixed, anchored by stakes or stumps with a height of 0,5 to 1 m. Manual application includes the digging of grooves with hoes, shovels and picks. The trunks are then placed in the groves. The pits dug mechanically allow greater contact between the trunks and soil (Photo 38). The space between the logs and the surface should be filled with soil to prevent the overflow of water and sediments forming a retention basin at the top of the trunk where the flow and sediments are retained *(Robichaud et al., 2008b)*. The distance between the trunk barrier depends on the slope angles. If burnt areas are very large and there is a large surplus of burning wood, impossible to sell, or if the tree trunks are irreparably burned, they may be used as barriers. This is done through the cut down and placement of trunks and other clear felling debris in the top of the soil, propped up by stakes or by the stumps (part that is left in the soil

Photo 38. *Log barrier fitted in the terrain as a antierosion measure (www.markitforestry.com).*

linked to the root system after the trees cut down). The burned logs can be tied to the stumps or left untied. This solution is only possible if the forest stands were planted at regular intervals, and if it is possible to put the logs perpendicular to the direction of the steepest slope angles. Where such an arrangement is not possible, cuttings should be used. The regular spacing of these trunks lying on the ground prevents an excessive accumulation of ashes, and forms a barrier that will limit the continuity of overland flow and sediments at slope scale, therefore reducing the losses of ashes and nutrients.

In some cases, log erosion barriers are not applicable, since the burned forest stands still have a commercial value and the trees are only clear felled and removed after the first rainfall events took place, and the broad of the degradation processes impacts has occurred. The reasoning for the late cut and removal of trees has to do with the loss of commercial value if the wood is contaminated with ashes.

Ad. (2) Straw wattle barriers compared to the logs have the advantage of being flexible for better adaptation to the ground surface (Photo 39). Barriers are usually placed in areas prone to the occurrence of low intensity overland flow or at the side of the slope, to retain small quantities of suspended sediments *(Robichaud et al., 2000)*. These barriers can also replace the logs when they are scarce or do not exist. They are made of an external skeleton of metallic mesh or nylon wool which is filled with straw or wood debris, porous structures that retain the runoff and reduce the flow velocity. The form of implementation is similar to the log erosion barriers. These structures are typically 0,25 m in diameter. The 0,6 m at each extremity can be folded upwards in direction to the top of the slope to increase the capacity to retain sediments *(Robichaud and Brown, 2005)*. Like the log erosion barriers, these nylon/metallic mesh tubes are placed along the contour of the slope and anchored with cuttings. The resistance of these barriers depends on parameters such as rainfall after installation, the density of the installation, the topography and soil erosion rates.

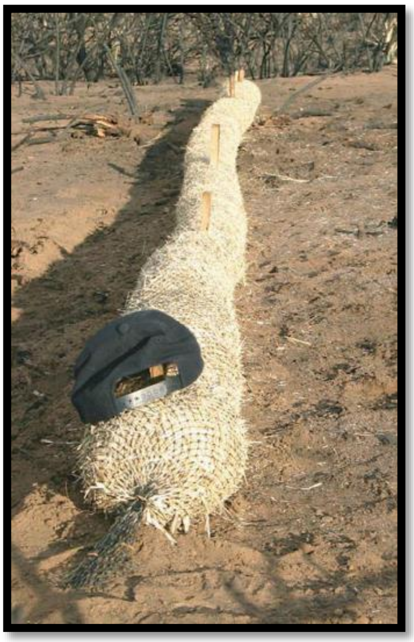

Photo 39. *Straw wattle as a antierosion barrier fixed by pins to the terrain surface (Ferreira et al., 2014).*

Robichaud (2005) syntethized that erosion barriers seemed to be effective only for the low-intensity rainfall events, and not for the more erosive high-intensity ones. By comparing straw and log or shrub barriers at the same burned sites, *Wagenbrenner et al. (2006)* and *Fernández et al. (2011)* checked that mulch was more effective. *Wagenbrenner et al. (2006)* checked that more than 30 % of the barriers were not in good contact with the ground or off-contour, mean that is very important to built-up all the barriers well contacted with the surface of the terrain.

These ex-post techniques involving biomass increment for erosion prevention, either by mulching, seeding and/or log and straw wattle erosion barriers, should be applied in the most vulnerable sites, at appropriate densities. These would represent a minor fraction of the total fuel load of vegetation recovered forest areas, representing a minor contribution for fire risk increment in subsequent years.

7.2 Ecology restoration and Revegetation

Restoration is a process to carry out the recovery of a degraded ecosystem, changing the successional trajectories of early post fire environment stages toward later successional stages dominated by more resilient species (*Valdecantos et al., 2009)*. The results can be perceived at long-term rather than at short-term periods. For *Cortina and Vallejo (1999)*, the main objective of restoration is, besides to maintain the water and the soil in place, to induce an increase in biodiversity and in the resilience of the vegetation against forest fire *(Vallejo et al., 2006)*. Trees have a role to reduce the wind speed inside the forest stand and to limit understorey vegetation growth, and should be maintained, ensuring the appropriate disruption in the vertical and horizontal fuel continuity. In terms of forest planning, preference should be given to deciduous broadleaved and mixed forests, usually less fire prone than plantations of exotic species. Afforestation policies promoting large scale monocultural stands in former agricultural areas is highly detrimental in terms of fire hazard at the landscape level. Thus, priority should be given to the creation of mosaics of smaller (less than 30 ha) non-contiguous forest patches (*Moreira et al., 2011*). Study of *Regueira et al., (1999)* showed, that hardwoods and mixtures of different species show a low risk index around the year.

The following recommendations for the establishment and management of planted forests can be derived: At the stand scale, clearing natural vegetation should be avoided prior to planting; where possible, the planting of native tree species is preferable; and the introduction of structural and species diversity of canopy trees (i.e., mixed species plantings) and in the understorey (via retention of pre-existing or naturally regenerating forest species) are desirable to the extent that this does not significantly compromise productivity of the principal tree crop of Eucalyptus trees. At the landscape scale, the protection and enhancement of remnants of natural vegetation should be an explicit aim; the creation of mosaics of stand ages and tree species is recommended as this can enhance biodiversity across the landscape; as is the establishment of corridors linking habitat patches, including forest corridors, non-forest corridors, and riparian corridors *(Brockerhoff et al., 2013)*.

Valdecantos et al. (2009) recognized that the combination of agricultural land abandonment and wildfires led to a shrubland landscape dominated by poor in resprouters species. The major goal in the management of these areas should be to reduce both the fuel loads and their continuity. At the same time, the resilience of the ecosystems should be increased by introducing resprouting species, which will decrease the presence of some highly flammable seeders (i.e. *Ulex ssp.*). In the revegetation they can occur naturally after fire, but mostly due to a variety of strong exotic resprouter *E. globulus*, that is far more successful compared to the native resprouters *Quercus pyrenaica* (Pyrenean oak), or *Q. robur*, which are; *a priori*, better prepared to support the passage of fire, as they have high germination rates and high or medium resprouting intensities. Strong resprouter kinds of bushes represents the species that develop a large amount of resprout biomass after fire, such as *Ulex europaeus*, *U. gallii* (Western gorse) and *U. minor* (Table 6).

The problem should be directed to the combination of agriculture land abandonment, exotic plantations, wildfires and mild rainfall years. The choice of species used in revehetation must be based on phyto-bio-geographic criteria (e.g. *Martínez, 1987*) and take into account climatic, edaphic, biological and economic factors. The technique consists of introducing a resprouting specie, use the varieties of mulching practices (Chapter 7.1.2.1) around the planting holes. This will protect the soil surface with a mulch layer, reduce both the soil surface temperature and the germination of competing seeds while increasing the soil water content, especially in the driest periods *Valdecantos et al. (2009)*.

Common name	Scientific name	Origin	Germination after the fire	Resprouting intensity
English Oak	*Quercus robur*	Native	Medium	High
Pyrenean Oak	*Quercus pyrenaica*	Native	Medium	High
Silver birch	*Betula pendula*	Native	Low	Medium
Sweet chestnut	*Castanea sativa*	Native	-	-
Common Gorse	*Ulex europaeus*	Native	High	High
Western Gorse	*Ulex gallii*	Native	High	Medium
Dwarf Gorse	*Ulex minor*	Native	High	Medium
Elderberry	*Sambucus nigra*	Native	-	-
White Spanish Broom	*Cytisus multiflorus*	Native	High	Medium
Hairy-fruited broom	*Cytisus striatus*	Native	High	Null
Besom Heath	*Erica scoparia*	Native	High	High
Cornish Heath	*Erica vagans*	Native	High	Medium
Broom	*Genista berberidea*	Native	High	High

Table 6. *Trees with good germination and resprouting intensity after the fire. Information for Castanea sativa and Sambucus nigra are not known (Reyes and Casal, 2008).*

Tree planting should be performed perpendicular to the steepest slope angles. In the case of very steep slopes trees can be supported by poles. Tree planting should be performed using minimum tillage techniques *(Navarro et al., 2005)*, which consists on digging small pits where the seedlings are introduce. The small pits should be made manually for slopes steeper than 21 % and locations with highly eroded soils. On the hillsides with a slope between 5 and 20 %, the plantation can be performed mechanically. Tree and bush combination is up to the landowner and his preferences, in case of erosion threat is effective way to choose some of the fast growing bushes in combination with grasses and mulching measures (Chapter 7.1.2.1). This can be applied in the perpendicular lines to the slope, about two meters wide; depends of the possibilities at the land situation. This solution in combination with basic terrace preparation based on log, or wattle barriers (Chapter 7.1.2.3) should enough stabilize the soil erosion threat, increase the ecological value of the land and keep its soil qualities. In the way of land reclamation could be partly understorey greenery work into the soils by mulching, or cutting machines for increase the nutritional qualities; it is highly necessary to keep all the green material at the land, terrace, or whatever our situation offer. Between our founded “restoration green lines” we are going to plant our target tree specie. If is there still necessity for pulp production and our interest is based on *E. globulus* cultivation, it may be done in combination with Betula pendula, or Castanea sativa tree species (Table 6); e.g. there is an information about the effective energy evaluation of *B. pendula* specie, this typical pioneer tree is able to produce about 120 – 140 m^3 / ha / year of firewood, in this concept we are taking in account the rotation about 15 years, therefore the same as for the Eucalyptus trees *(LP, 2016).*

There is a different approach according to the land situation and composition, in the meaning of: (1) tree, bushes and grasses ratio; (2) land relief, exposition, orientation and altitude; (3) landowner priorities and financial possibilities. In general way the higher biodiversity is able to better resist against the fire and erosion disturbances, also against pests *Thompson et al. (2009).*

7.2.1 Biodiversity - Follow up of land possibilities

Key considerations for enhanced biodiversity outcomes can be placed within a framework encapsulated by the following questions: (1) What is the land use prior to planted forest establishment? The conversion of abandoned agricultural or degraded land with limited conservation value is not expected to have negative impacts on biodiversity, and it may have positive effects on biodiversity. By contrast, the conversion of natural vegetation, particularly if it contains significant vegetation or threatened species, should be avoided. (2) Are natural areas protected? Such areas are likely to be of high conservation value and, where possible, they should be exempt from conversion to planted forest and be set aside for protection. (3) What management of biodiversity and, inparticular, threatened speciesis being undertaken? This should include surveys of biodiversity occurring in the land holding, consultation with local conservation authorities and experts, and the development and implementation of biodiversity management plans. (4) What is the identity of the tree species planted and is it a native or introduced species? Planted forests often involve the cultivation of introduced species. While this does not preclude opportunities for biodiversity conservation, the use of native trees typically provides better habitat for other native species. (5) Is understorey vegetation present and are there opportunities for its enhancement? Presence of understorey vegetation can enhance the value of planted forests as habitat for a wide range of species that benefit from the increased structural complexity and the availability of resources not provided by the canopy tree species.

7.3 **Land and forest management optimalization**

Fuel management is not only devoted to limiting wildfire spread, but also to lowering fire impacts on human resources and assets. This new forest management and planning vision also supposes increasing preparedness and response capacity to fire events, especially at the wildlande-urban interface *(Maillet et al., 2010)*. In the latter, forest and urban planning should be tuned together and citizens living in fire risk areas should also become part of the solution, by building and preparing their homes for the arrival of fire, as well as being well-informed for fire-response planning (defence and evacuation). Under moderate to severe fire weather conditions, fuel management should be focused on increasing the fire suppression options and effectiveness by limiting fire ignition and fire spread in strategic locations. This is what we call compartmentalization, the division of the landscape into blocks that should set a maximum fire size.

Both in fuel breaks and area-wide treatments (Chapter 7.1.1.5), there is a wide range of possibilities to maintain or promote lower fuel loads, including silvicultural techniques (Chapter 7.3.1), agricultural and grazing management (Chapter 7.3.2), or even the use of fire (Chapter 7.1.1.4). These treatments will increase the opportunities for safe and successful fire suppression options and reduce the fire severity on the ecosystem or valuable assets *(e.g. Rigolot et al., 2009)*. Several surface fuel management techniques are available including mechanical clearing (increasing fuel compactness), phytocides (limiting plant growth), prescribed burning and controlled grazing (reducing fuel load) *(Etienne et al., 1994; Valette et al., 1993; Xanthopoulos et al., 2006)*.

7.3.1 Growth models as a silviculture tools

The fountainhead of contemporary forest economics pertaining to timber rotations can be traced to the financial model pioneered in the mid 19th century by Martin Faustmann (1849), who was a German forester. The Faustmann model advised the woodland manager to select when to cut timber by maximizing the discounted sum of income, taking into account the growth rates of a forest stand, the prevailing interest rate plus the opportunity cost of carrying the land for timber production purposes by Mitra and Wan (1985). Since its formulation in the 19th century, the Faustmann model has served as a powerful tool for guiding forest economic analyses *(Brockerhoff et al., 2013)*. Uncertainty in the Faustmann model was explored by *Reed (1984)*, who analyzed forest fire risk; Willassen (1998), who included stochastic effects on the forest value growth; and *Reed (1993)* and *Reed and Ye (1994)*, who explored the option value associated with amenity services in old-growth forest stand. Following *Hartman (1976)*, the importance of nontimber benefits and the effect of forest-wide considerations have been addressed by a number of authors *(Strang, 1983; Paredes and Brodie, 1989; Snyder and Bhattacharya, 1990; Swallow et al., 1997, Koskela and Ollikainen, 2001)*, but in all cases the analysis is constrained by the structure of the Faustmann model; graphically explained (Figure 13). Specifically, nontimber benefits are always considered to be a direct function of the age of trees.

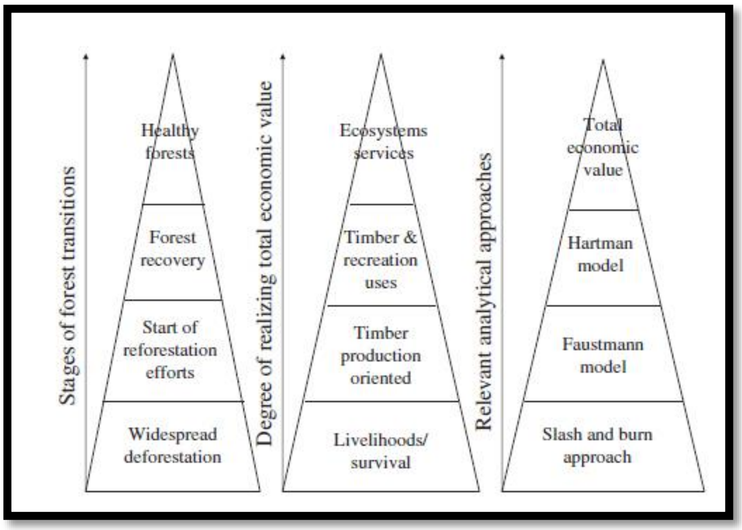

Figure 13. *Relation between silviculture methodology, forest state and its final resources for harvest (Wang, 2013)*

7.3.1.1 Non-Timber harvest as a direct result of timber quality

This is a simple restatement of Faustmann formula. It states that it is optimal to harvest a forest stand when the marginal benefit of delaying harvest is equal to the opportunity cost of holding on to standing trees. Similarly, if the flow of nontimber outputs is considered, the Hartman rule can be derived from the cutting condition. Following the Faustmann–Hartman framework, replanting activities follow immediately after harvest. Nontimber benefits are obtained from the flow of services provided by the forest ecosystem (Chapter 7.4) and are specified to be a function of timber biomass. As the harvest is clearcut, nontimber services are indirectly a function of the age of the trees. The management objective is to maximize the value arising from both the timber and nontimber benefits of the stand by choosing the optimum sequence of clearcut harvests.

7.3.1.2 Non-Timber benefits as a result of ecological resources

The specification of nontimber benefits used in this chapter assumes that these are indirectly derived from the state of the forest. They are affected by harvesting activities that lead to discontinuities in the ecological resource stock. This specification allows a more general representation of the interactions between timber and non-timber benefits than is possible in the Faustmann–Hartman models. The optimality condition derived includes an additional term that represents the marginal value of the ecological resource as harvest is postponed. This extra term accounts for the disturbance effects of the logging operations. It shows that, when the disturbance effects are small it will be optimal to combine short rotations with high levels of ecological resource stock. When disturbance effects are large it will be optimal to choose longer rotations. When the habitat destruction effect dominates, the postharvest level of the ecological resource is reduced to some minimal (constant) value. This means that the shadow price of the ecological resource stock just before the harvest is zero and the optimal cutting condition is a Faustmann–Hartman rule. The optimal harvesting age will however be influenced by the fact that the non-timber benefit depends on the ecological resource stock rather than the age of the trees. This result is driven by the fact that carrying capacity of the ecological resource is assumed independent of the forest biomass *(Touza, 2008)*.

7.3.2 Agriculture and pasture practices

For example, the European Agriculture Fund for Rural Development *(Act No. 1698 / 2005 Coll.)* could contribute to achieve these objectives (policies enabling the improvement of the socio-economic conditions of people living in rural areas, promoting new immigration to these regions, and implementing rural development policies that foster activities contributing to reducing fire hazard, such as agriculture and livestock grazing.) in disadvantaged rural areas by: (1) improving the competitiveness of agriculture and forestry activities; (2) improving the quality of life by the diversification of economic activity, and (3) supporting land management strategies. There is a need to define policies to maintain farming activities in areas where landscape planning identified as priority sites for fuel reduction, such as areas surrounding villages or pastoral activities in landscape fuel breaks *(Moreira et al., 2011)*.

Beylier et al. (2006) showed the successful contribution of sheep grazing to fuel control on both a fuel break network and neighbouring areas in the Luberon Natural Park (France). *Thavaud (2009)* provided practical guidelines for reactivating rangeland management in various ecosystems of the Mediterranean area. They combine new establishments of livestock farmers in fire prone areas, together with consolidation of existing animal farming. Agricultural cultivations and other land uses can be included in fuel break networks as far as they provide a low flammability cover type during the fire season. In areas where there are no possibilities of promoting agricultural or pastoral activities, one other alternative to manage shrublands is to carry out afforestations with less fire prone tree species (Chapter 7.2).

7.4 Non-Timber resources

Wide-scale solution for environment stabilization could be just a different point of view at the forest status as a landscape unit, progressive policy and human need fit our forests to the position of produciton unit, where is no more need of nothing else. For ecosystem stabilization and general human welfare is necessary to realize further purpose and possibility of the forest unit in our landscape, this is generally applicable worldwide with many different ways of realization according to the landscape and human need at the place. With existing solutions mentioned in the foregoing chapters, which are basicly explained for the Galician landscape and with the (non-)timber sence, there exist a very effective way of forest use in „modern“ way.

Non-timber follow up in very sensitive explication to environment is done by *Laarman and Sedjo (1992),* they summarized the goods and services that forests can provide for human welfare in five categories: (1) protective services and influences, such as soil and water conservation, climate regulation as well as conservation of biodiversity; (2) educational and scientific services, where forests are used in research and teaching to obtain and transmit basic knowledge; (3) psycho-physiological influences, including tourism, recreation, inspiration for art, religion and philosophy, etc.; (4) consumption of plants, animals and derivatives, referring to timber, fuelwood, and other derived products from forests; and (5) source of land and living space. When considering all functions of forests, such as commercial, protective, and recreational, forests serve as sources of livelihoods, wealth, income, and recreation, as well as educational and spiritual purposes.

Therefore, corresponding to hierarchy of *Maslow (1943)* for human needs, the various functions of forests may be arranged in a more progressive order as follows: (1) fuelwood for energy; timber for subsistence livelihoods, (2) wood production to supply raw materials for housing, construction, and further processing into a variety of products, (3) forests formultiple uses, including timber and non-timber benefits, and (4) forests for recreation and ecosystem services as well as timber and non-timber uses.

Back to the *Hartman (1976),* he recognizing the importance of various non-timber values, modified the Faustmann model by articulating that many non-timber values, such as amenity values, have the effects of delaying timber harvest. Hence, the

Hartman rotation tends to be longer than the Faustmann rotation (Chapter 7.3.1.1). However, it needs to be pointed out that the prolongation of a timber rotation is not the only way of increasing non-timber values. Strictly speaking, the degree of biodiversity in a forest serves as an important indicator of non-timber values. In view of this factor, some early-succession habitat may require a reduction in optimum rotation age *(Wang, 2013)*.

Theoretically, non-timber forest products (NTFP) could also be produced commercially and then marketed by forest owners, tenants and businessmen. Additionally, forest legislation explicitly does not apply to the commercial cultivation of NTFP. Nevertheless, the NTFP can be still considered as a potentially important contribution to the economy and a significant market factor in rural areas. A large part of the NTFP (forest fruits, mushrooms, medicinal and ornamental plants) can be regarded as an alternative to agricultural production, and marketed as high quality organic products, produced to a great extent without any chemical inputs. Forest management for timber production combined with the production of NTFP could be taken as a kind of "symbiosis" between forest management with classical objectives (timber, environment) and simultaneously for forest production of a more agricultural type.

Galicia with its potent environment in the meaning of annual green increment *(Amil, 2007b)* offer great opportunity how to involve and icreas native tree and bushes species into the private forest production site. *E. globulus* even-aged stand could be cultivated by the side of other broadleaf trees and native bushes (Table 6), well designed site can involve incame from the NTFP (e.g. berries of *Sambucus nigra*, firewood of *Betula pendula*, nuts from *Castanea sativa* and other existing medical extracts of their combination, or just a mushroom collection) and its composition will always increas biodiversity, ecological value and such a good example can serve as a study site for further public interest and well of knowledge.

8 Discussion

Eucalyptus in Galicia and its cultivation bring by the time of thesis realization many questions, which seems to be further by the concepts one from each other. However, we realized that all of them are very closely related (i.e. such a domino effect), then the most important needs for the environment and social sphere were highlighted and elaborated with their solutions in different chapters. As there is much more things to solve around also the discussion of the eucalyptus cultivation in Galicia makes a lot of space for opinions, different solutions and their application, then we are able to find out here.

8.1 Wildfires

In general, the effects of wildfire on landscape may vary from region to region because of differences in local fire history, regeneration patterns among main land covers and topographic constraints *(Viedma, 2008)*. Finally, people's perception of the low value of burned areas reinforces these positive feedbacks leading to increased fire frequencies *(Blasi et al., 2004; Vazquez and Moreno, 2001)*. There is a social perception that burned areas are less valuable which, in the absence of proper conservation strategies, makes them more prone to land abandonment.

Therefore is necessary to build up proper fire prevention philosophy, for implemantation of measures and facilities, which lays on a set of infrastructures in rural areas, consisting in the creation of networks of fuel managed firebreaks, fuel management plots, creating a landscape mosaic, fuel managed strips along the forest roads and a network of water points, among others.

Landscape diversity acquires an enormous importance in the management before the fire, since the variety of landscapes and infrastructures can be planned so as to hamper fire progression, thus reducing the area burned (*Ferreira et al., 2014*). Rehabilitation and restoration are longer-term activities to repair access and to mitigate degraded areas that cannot recover to pre-fire conditions on its own (i.e. tree planting, noxious plant reduction, fuel control). Mainly is necesary to understand the fire and to have people, which suppose to reduce fire threat at the right place in the right time, as before as during and after the wildfire is done.

8.1.1 Fire unpredictability

Fire as a natural element will never follow the human rules, its behaviour variables like fire intensity or flame height are a direct consequence of surface and crown fuels *(Van Wagner, 1977; Rothermel, 1983)*. Therefore the assessment of fuel-related variables like shrub cover and tree cover can be of interest for the establishment of relationships with tree responses *(e.g. Moreira et al., 2007)*. Additionally, topographic conditions, such as slope and aspect, have a direct influence on fire behaviour *(Rothermel, 1983)*, but also on the vegetative conditions of each tree and surrounding vegetation. These existing facts can be followed for to predict the real fire threat, which makes our responsibility much higher in relation to application of mentioned measures (Chapter 7) and their realization in the open landscape. *E. globulus* shows as a high risk specie mainly during the summer time (i.e. risk index 4; Chapter 5.2), when all parameters, such as calorific values, flammability, dry winds, low environmental humidity and decrease of rainfall are most favorable for forest wildfires. The rest of the year, the risk index can become greater when this species is intermingled with other species, mainly conifers *(Regueira et al., 1999)*.

Existing studies should help to us in the fire intensity prediction; e.g. to the mentioned influence of topography (altitude, exposure, slope) can affect fire frequency and rate of spread. The causes behind these topographic effects can be grouped into fire ignition patterns, fire behaviour (in particular rate of spread), and fuel biomass. In fact, topography interacts with local wind direction, microclimates and, in turn, vegetation type, fuel loads and moisture content. Several studies have shown topographic influences on vegetation composition and structure *(Fontaine et al., 2007; Rescia et al., 1994)*, transpiration and desiccation conditions *(Rana et al., 2005; Van der Trol et al., 2007)*, vegetation dynamics *(Carmel and Flather, 2004; Mouillot et al., 2005)*, fire severity (Broncano and Retana, 2004), and post-fire vegetation regeneration *(Peñuelas et al., 2007; Baeza et al., 2007)*.

Moreover, there is some anecdotal evidence that certain land use/cover types with low fire hazard can turned into very hazardous ones under improper management. For example, permanent crops such as olive groves and vineyards, which will act as fuel breaks under correct maintenance (periodical removal of grasses and weeds), can facilitate fire spread when not properly managed. Anyway large fires are becoming more frequent, at least in some regions. Available evidence indicates that we do not have the technical capabilities to avoid large fires and that they will spread irrespective of land use/ cover planning under extreme fire weather. Even if we tried to increase our technical suppression capacity more, we would simply increase the level at which fuel accumulation creates fire danger conditions that surpass the new suppression capacity. The implication of this is that under certain climatic and fuel load conditions, wildfires will always occur *(Moreira et al., 2011)*.

8.2 **Land management**

Any attempt to create a more diverse landscape, requires a different strategy of land use, the development of a diversification of economic activities and probably a greater human presence in rural areas. The best solution is to promote the landscape diversity through the diversification of economic activities and assuring a higher level of judicious management over the territory, bearing in mind that there is a weak carrying capacity of ecosystems and that any exploitation will result in its degradation and loss of the environmental services they provide *(Ferreira et al., 2014)*.

Prescribed fire or controlled pastoral fire, or energy policies supporting the environmentally compatible use of renewable bioenergy potential from agriculture and forestry (agricultural waste, crop mix for biomass production, complementary fellings and residues from silvicultural activities and fuel management) may also contribute to reducing fire hazard, while providing job opportunities to rural populations. Appropriate use of fire by rural communities coupled with the development of prescribed burning undertaken by fire professionals may be used in integrated fire management (Silva et al., 2010).

8.2.1 Silvicultural practices

It is a fact and important necessity about the mix stand of forest. I would like to demonstrate the importance of mix planted production sites in this thesis, where will be more native broadleaf species standing by the side of *E. globulus* trees in combination with bushes and well maintained forest understorey (Chapter 7), because mature forests of broadleaved deciduous and mixed forests generally have a low fire hazard compared to pure eucalypt plantations, or mixed pine and eucalyptus stands *(Fernandes, 2009; Moreira et al., 2009)*. However, forest structure may be more important than forest composition in defining hazard *(Fernandes, 2009)*. In fact, differences between forest types may be explained by different fuel structures, e.g. the degree of canopy closure that limits the development of a grassy or shrubby fuel bed and maintains vegetation with high moisture content *(Gracia et al., 2002; Pausas et al., 2008; Vazquez et al., 2002; Zavala et al., 2000)*. There is some evidence that mature evergreen oak forests can even become „self-protective“ against wildfires, to the point of fire self-extinction *(Fernandes et al., 2010)*. In the case of some deciduous oak communities, the recovery process after fire is very low, and more than 50 - 60 years are needed to reach the prefire conditions *(Calvo et al., 2002a,b; Jacquet and Prodon, 2009)*.

Even timber rotation analysis has evolved over time, thanks to shifting societal perceptions of the values associated with forests, particularly due to rising concerns for the need to conserve nature, minimize adverse effects of timber harvesting on habitats and protect public goods attributes of forest ecosystems *(Wang and Wilson, 2007).* Then the optimal rotation period depends on the impact that harvesting has on the ecological resource, the ability of the ecological resource to recover, and the extent to which the carrying capacity of the system has been affected (*Touza et al., 2008*); these facts are mainly relaed with non-timber produciton priority, where the ecological resource may be the main background for whole non-timber profit in the meaning of money income and the environmental qualities.

Regarding management of planted forests for enhanced provision of ecosystem goods and services, there is no „one-size-fits-all“ approach. Due to the large number of different ecosystem services, the potential existence of trade offs among these, and site-specific and forest type-specific circumstances, recommendations need to be directed at the particular ecosystem service of interest. However, some generic guidance can be given. Planted forests that are well managed with consideration of the stand and landscape level recommendations above, and that are composed of a greater variety of tree and understorey species, are likely to provide desired ecosystem services to a greater degree than those that are not. A careful analysis of what functional aspects of biodiversity are relevant for the provision of specific services should point towards possible solutions. Improved communication between scientists, policy makers and forest managers is a critical element for a better understanding of relationships between forest biodiversity and ecosystem services and the relevant measures that can be implemented during forest management to enhance the provision of those services most relevant and valued by society from such forests *(Thompson et al., 2011)*.

On the other hand, there are various definitions for sustainable forest management. In the case of industrial forest plantations, short rotations and intensive management prescriptions have aroused suspicion in certain spheres *(Gerber, 2011; Kröger and Nylund, 2012)*, thus demanding some sort of sustainable management. Thus, forest managers and owners must have precise assessments of sustainability, as well as the capacity to predict the effects of management regimes. For plantation forests, some studies have defined sustainability incompletely, for example by only focusing on the maintenance of the production capacity of the site in the long term *(Watt et al., 2005)*, or by focusing on changes in certain soil properties and the production capacity of the site as a consequence of repeated rotations *(Evans, 2009)*. Eucalyptus plantations cause a great deal of controversy in some areas for different reasons *(Balteiro, 2007; Lomba et al., 2011; Cancela et al., 2012)*. One solution for relieving these problems would be to tackle their management by integrating other aspects which could make them more attractive to other stakeholders (Chapter 7.3 and 7.4). One way of carrying out this management would be to explicitly introduce sustainability indicators, and, thus, to select those feasible alternatives which are most sustainable. Is necessary always bearing in mind that the selection of indicators has been subjected to the possibility of quantifying them in the different management alternatives considered *(Giménez et al., 2013)*.

When deforestation reaches a level of crisis, citizens start to search for measures to address the adverse effect of resource degradation and, oftentimes, efforts are made to rehabilitate degraded land through reforestation for timber production. During this period, the Faustmann model may be applied. Along with economic development, concerted reforestation efforts lead to forest recovery; meanwhile, heightened awareness of a string of values other than timber gains momentum. This is a stage where the Hartman model is applicable. When citizens become well-off, forests are restored to their healthy state. People value to a greater extent recreational opportunities and ecosystem services and they demand the realization of total economic values from the forest (*Wang, 2013*).

8.2.2 Non-Timber production

Multifunctional forestry is a globally accepted way of forest land management. Nevertheless, regarding production, the attention is historically, prevailingly focused, in many cases, on market timber production. Non-timber forest products (NTFP) were not treated as an important commodity in many countries and communities. The situation has been gradually changing which corresponds to the principles of multifunctional sustainable forest management with the aim to optimise the delivery of different products and services to the respective societies while keeping the sustainability of the forest ecosystems *(Sisak et al., 2015)*. Forests possess multiple functions beyond timber production. Forests have the capacity to meet citizens' growing needs, expectations, and a range of uses. Thanks to a rising standard of living in many countries, forests are becoming essential places for multiple uses. People in advanced economies are increasingly relying on their forests for goods and services far more than timber and wood products. In particular, forests provide an ideal setting for outdoor recreation. As household income levels increase and human welfare improves, recreational use of forests and demands for various environmental services tend to increase *(Hyde et al, 2003)*.

It is increasingly recognized that the economic values of forests comprise benefits ranging from timber and various non-timber products to a host of less commonly measured services and functions including eco-tourism, water conservation, carbon sequestration and biodiversity. *Kant et al. (1996)* examined the role of forests in economic welfare in the context of developing countries. They focused on non-timber contributions of forests to villagers and concluded that financial returns from non-timber uses played a crucial part in rural economies. Forests provide food, fuel, fibre, timber and other NTFP. Although any individual NTFP is usually economically less significant than timber, as a group they sometimes contribute more value per hectare than timber and big benefit is that NTFPs are often consumed locally *Kant et al. (1996),* what is an great issue for rural environment.

As a good help in landowners decision in the meaning how much to involve the NTFP into his production site, could be opinion of *Von Thünen (1826),* which says that the distance of the land from the market should be viewed as a crucial determinant of land value. In a nutshell, geographical location of a piece of land relative to the market is key to land value. Sometimes it is an issue for those once with less facilities for proper maintenance of their badly accessible forest land, this could be a help in the decision how much to involve the main production tree specie *E. globulus* and then to be focused on the NTFP and its income in combination with increasing biodiversity and forest stability by the side (Chapter 7.2 amd 7.4).

Forest offers human beings a diversity of uses. Therefore, within a given forest, it is entirely possible that values can compete with one another *(Aumann et al., 2007)*. This means that the selection of an appropriate analytical framework is just the beginning of a process to search for an understanding of the problems and circumstances surrounding the way the resources are managed to meet various human needs *(Lavoie, 2005)*.

8.2.3 Reintroduction of rural life and its policies

Population decline, agricultural and pastoral land abandonment and policies promoting forest cover, particularly in former agricultural land, are driving the “rural exodus syndrome” *(Hill et al., 2008)* and causing a widespread increase in vegetation biomass over large areas. This trend can only be counteracted effectively through the creation of policies enabling the improvement of the socio-economic conditions of people living in rural areas, promoting new immigration to these regions, and implementing rural development policies that foster activities contributing to reducing fire hazard, such as agriculture and livestock grazing. These policies are mainly related to agricultural, rural development and economic issues, rather than forest management.

Whole abandoned villages are not exceptional fact, mostly situated in the inland and mountain areas, then exist municipalities offering these whole villages, or just a single houses for sell in abandoned areas. There is more than one case of existing programs for reintroduction of rural life, when you as a person interested about those offers may buy in most of the cases old farm house with long history and couple of hectares with very good soil qualities! It is more and more popular for modern young families to look forward for this kind of opportunities and in some cases are existing whole partly sustainable villages managed by newly coming population. These facts can increase local landscape biodiversity, introduce distinct land management also with mixed patches of eucalyptus production sites, local market welfare and bring freshness for the local economy.

In general, there is a need for reinforcement of the existing laws and regulations on fuel management around buildings and villages, either through farming or other types of fuel reduction techniques. Stakeholders and managers have to realise that fire-fighters can extinguish most of the fires, but when there is one beyond the extinction capacity, or when the firefighting system collapses because of the large number of concurrent ignitions, a large area will be burned because of the high fuel load resulting from successful fire suppression in previous years. The success of policies and management has to be evaluated firstly by the amount of damage caused, rather than by the number of hectares burned. Reducing fire damage will be attained by reducing fuel loads and the vulnerability of the values at risk. This means better planning of locations of houses and villages, promoting policies to avoid the increase of the rurale-wild-land interface, greater awareness of citizens, and the enforcement of existing laws and regulations on fuel management around buildings and villages *(Silva et al., 2010)*.

8.3 **Biodiversity and its influence to productivity**

Plantations of native tree species are generally preferable for forest biodiversity although plantation forests of introduced trees can also provide habitat for native plants and animals *(e.g., Brockerhoff et al., 2003, 2005; Eycott et al., 2006; Pawson et al., 2010)*. Eucalypts are introduced species almost everywhere where they are planted. Several other factors are important when evaluating the effects of eucalypt plantations on biodiversity *(Tassin et al., 2011)*. Overall, it is generally accepted that planted forests, especially those of introduced tree species, are typically less valuable for biodiversity than natural forests. Therefore, the trends of on going loss of natural forest and increasing proportion of planted forest will undoubtedly have far reaching effects on biodiversity especially for forest dependent species. Furthermore, as plantations will increasingly represent a major proportion of the total forest cover in many regions, the demand will grow for their contribution to the conservation of forest biodiversity and the provision of ecosystem goods and services that depend on biodiversity (Chapter 7.4).

(Phalan et al., 2011) mention an interesting term; „Land sharing“ what means, that net benefits for biodiversity conservation are greater when production and conservation occur on the same land. His though should complement the law *Act No. 10 / 1995 Coll.* (i.e. Spatial Planning in Galicia), which is about the improvement of national nature conservation policy in relation to the realisation of the EU - Habitat directive Natura 2000 *(Jongman and Kristiansen, 2001)*. Therefore, in the Land sharing meaning and application of terrain improvements (Chapter 7.1), ecology restoration and revegetation (Chapter 7.2), and with appropriate management (Chapter 7.3) is possible to achieve proper spatial planing under the law in Galicia and in further scale of Europian Ecological Network (EECONET) with keep *E. globulus* trees and its cultivation, mean pulp production and also other non-timber products included in mixed stand production sites.

(Balvanera et al., 2006) find out significant positive relationships that biodiversity have been documented for primary and higher level of productivity, erosion control, nutrient cycling and ecosystem stability. In a major review specific to forests, *Thompson et al. (2009)* concluded that the ability of forests to resist environmental change and to recover from disturbance is related to biodiversity from

genetic to landscape scales, and that plantation forests are usually less resistant and resilient than more diverse natural forests. So, diversity of species in planted forests has been shown to be directly related to productivity.

For example, a review of 21 studies that examined the effects of biodiversity of trees and understorey species on the productivity of forests found a positive relationship in 76 % of cases *(Thompson et al., 2009)*. Despite the wide range of species mixtures tested, these experiments produced remarkably consistent results with a global pattern of higher stem volume or biomass in mixed plantings than in pure Eucalyptus stands. Productivity gains were primarily attributed to above ground niche complementation (improved use of light resources due to complementary canopy structures), higher soil fertility (increased nitrogen supply by associated species), and lower understorey competition. However these trials also showed that not all mixtures were equally more productive than pure Eucalyptus forests and that both, species composition, functional composition and diversity, and the spatial design of mixed species plantations need to be considered. These results indicate that by increasing tree species diversity in planted eucalypt forests, significant productivity gains may be obtained either via enhanced growth or, indirectly, due to lower herbivory damage. Functional diversity and composition of tree assemblages are probably important factors that explain productivity and related responses.

Potentially even greater future importance is the expectation that more diverse (mixed-species) forests are more able to withstand or adapt to climate change. This is because in mixed forests there is a greater probability that some tree species will be able to persist as climates are changing in terms of temperature, rainfall, etc., than would be the case in forests composed of a single tree species *(Seppälä et al., 2009)*.

Consumer diversity was also found to be related to plant diversity. In a recent meta-analysis based on 320 case studies *(Castagneyrol and Jactel, 2012)*, it has been shown that the diversity of arthropods, reptiles and amphibians, birds, and mammals significantly increases with plant diversity. Twenty five of these correlations between plant and animal species richness involved Eucalyptus forests *(Fonseca et al., 2009)*. These studies reveal that vertebrate diversity and arthropod diversity are positively correlated with the diversity of plants (principally understorey vegetation) associated with eucalypt plantations. There are numerous other linkages between forest diversity and the functioning of forest ecosystems and related ecosystem goods and services that are relevant to humanity, including effects that benefit adjacent ecosystems beyond the forest *(Thompson et al., 2009)*. For a general review of ecosystem goods and services that are provided by plantation forests, see *Bauhus et al. (2010)* and *de Groot and van der Meer (2010)*.

8.4 Forest future driven by human need

Wang (2013) mention in his text couple of predictions for forest future, which of course cannot be generally applied in global scale. Anyway, one wide spreaded fact is the evolution of digital technologies and its availability, it can decrease need of the writing and printing paper. His opinion makes me feel, that we can always start with ourselves and change our habits of demands for the paper in any existing form. I asked my self, that all this big pulp production must have demand, as a market rule says, that if buyer does not exist, there will be no more stock for its non existing demand. Paper is our daily company and it is up to us how much we will think about its necessity in daily habits, because if not in Galicia, there will be another country and its landscape under the influence of intensive policy of ENCE, or different company, which will provide paper luxury for us.

Next vision of *Wang (2013)* is about the increasing of population and its need of recreational opportunities in the nature as well in the forest environment, this may be more related to the city agglomerations more than to the rural Galician lifestyle. These urban citizens have the tendency of demanding a significant shift in forest management away from high-ecological-impact operations towards environmentally benign practices, resulting in higher costs of timber production and wood delivery. These visions can move view of timber wood from extensively and intensively tagged commodity to the position of highly evaluated stock with less spreaded production sites, what could leave more environmental space with advantages for natural parks, mixed stand of non-timber production forests and climax stands of native tree/bush composition.

There is an interesting opinion about to establish institutions that are designed to create the conditions for socially optimal resource outcomes. Many economic agents are involved in forestry and their interactions are highly complex. Recognition of this fact calls for applying the New Institutional Economics (NIE) approach. Then under the NIE framework, social institutions are expected to play an important role for the proper management of forest resources (*Wang and van Kooten, 2001*). So, Public Administration must share responsibilities with local population in order to propose and implement successful forestry measures in land planning, especially in areas lacking a clear pattern of forest use and management. The Public Administration should particularly encourage bottom-up models of land allocation and planning, such that the rural population could take over the role of land investors more easily and could design and choose a model of forest use and management that is balanced with their land demands *(Pérez and Vicente, 2008)*.

9 Conclusion

E. globulus is a great tool for timber independence, but must be maintained in a responsible and educated hands, there will be always necessity for pulp production, that mean the Galician case of course is not the only one region affected by its cultivation (e.g. China and Brasil). If the goal of this thesis is to improve the situation about the Eucalyptus cultivation in Galicia, it is necessary to step back from the regional scale and see all further relations and circumstances of whole process . If that would not be Galicia region providing its amount of pulp production, there will be another one part of the world, landscape under the influence of intensive Eucalyptus cultivation. Size of existing companies (ENCE, IKEA, etc.), their capital possibilities and freedom in the market, allow them to drive their aggressive policy all over the countries. Size of their effect grow over the small scale of local needs, into the scale of global demand; i.e. necessities of all of us are driving the company policies far away out of our borders, it makes me think about the importance of local sustainability, which will limit high production of dominant companies and will increas small local production and its economic situation, such a importance for wider agricultural production (vegetable, fruits, etc.).

Anyway, if there is no way how to change the actual situation from up to down direction (i.e. changes focused on the ENCE policy and wide influence), we should made it from down to up direction and try to solve the effect of Eucalyptus cultivation at our won lands. Whole paper should be as a guide, which wants to mention what is wrong and what to do with your production site of *E. globulus*, each one mentioned problem could be studied even much further with existing studies, which could be easily founded in the chapter of references. From my point of view local precipitation hand in hand with good soil qualities offer great conditions for general forest production. In combination with well informed population, which will provide good quality management at their own land, it could make great opportunities for cultivation of *E. globulus*, or *E. nitens* with native tree and bush species. Proper way how to inform owners of the land with know-how based on the existing studies should lead their vision forward to increase their independence from enormous leading companies and it can also make it interesting for those young people, which are leaving rural life toward the city life. If is there a good intention, there is also good result.

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