Soil Degradation Risks in Planted Forests

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Foreword

Forest ecosystems are extremely important in the densely populated Basque Country, which is subjected to strong anthropogenic pressure both from the general population and from industry, particularly in the Atlantic watershed. Forests cover 55% of the land in the Basque Country and are essential for protecting our soil and water and of vital importance for maintaining biological diversity. However, it is also true that forests represent an important source of income for the Basque Country. Some 80% of the forest land is owned by more than 20,000 private owners, and forest stands are of enormous importance to the rural development of the country. Our forests provide 13% of all agrarian production in the country, and 90% of forestry activities involve radiata pine. Furthermore, the forest-timber sector directly provides more than 3500 jobs in the country and is therefore recognised to be of central importance by the Deputy Ministry for Agriculture, Fisheries and Food Policy of the Basque Government.

Thanks to support from the government and the Basque entrepreneurial spirit, the forest landscape has increased greatly in the last century so that the country is now predominantly afforested. Rather than having to focus on increasing the forest cover, we must now concentrate on maintaining and sustaining the forests and increasing the quality of the products and services that they provide.

The two keywords associated with the development of forest-timber initiatives by the Basque Government are *multifunctionality* and *sustainability*.

The *multifunctionality* of a forest ecosystem refers to the provision of a physical environment that enables development of a culture and also shapes that development. We hope to improve the quality of the forest ecosystem and the provision of basic resources (principally water, air and soil), recreational space and forest products (which form the basis of the economic activity of the country because of the top quality of the products and the intense land management). The Government is developing policies associated with all of these aspects of forestry - via basic research (University and NEIKER), applied research (NEIKER) and in development of the forest-timber sector (HAZI).

Sustainability refers to the capacity of the sector and forest ecosystems to provide the aforementioned multifunctionality over time, as reaching the present status has involved risks and a great deal of investment that must be maintained and increased. Government policies are also being developed within the three previously mentioned activities in order to guarantee sustainability.

In accordance with the European Commission, the Basque Government is following a strategy of protecting soils and it defends sustainable forest management as the best means of preventing the degradation of forest soils. For this purpose, the Government has invested numerous resources and efforts via different Departments to achieve and certify sustainable forest management. In order to demonstrate the Basque Government's commitment to this type of management and to learn from other European regions where forest plantations are also important, we have decided to publish this book and thus support the International Workshop on Soil Degradation Risks in Planted Forests held in Bilbao, Basque Country.

Bittor Oroz Izagirre

Vice-Minister of Agriculture, Fishing
and Food Policy of the Basque Government

This book compiles the proceedings from the FORRISK International Workshop on Soil Degradation Risks in Planted Forests, held in Bilbao on 10th September 2014 under the auspices of IUFRO and the European Commission. It was organised by NEIKER Tecnalia in collaboration with the Atlantic regional office of the European Forest Institute, EFIAtlantic, with the financial support of the Interreg SUDOE IVB FORRISK Project.

Edited by:

Ander Arias González
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Forward

Ted Farrell

Throughout history, the consequences of man's activities for soil stability and regional hydrology have been learned through catastrophe. Deforestation has, all too often, been the cause of soil degradation. The droughts which followed the felling of the great cedar forests of the Fertile Crescent, in Mesopotamia, more than 4,000 years ago, are mentioned in the Epic of Gilgamesh, perhaps the first great work of literature. In the times of ancient Greece and Rome, erosion and flooding were widespread in the Mediterranean Basin. The link with deforestation was understood by many. The Greek philosopher, Plato, noted the erosion of the soil which resulted from deforestation in Attica in the 5th century BC. Much more recently, large-scale felling of Alpine forests in the 19th century resulted in widespread erosion and flooding, referred to as the "Alpine torrents". Sadly, we are slow learners and still today, uncontrolled deforestation has led to catastrophic soil erosion and flooding all around the world, from Haiti to Malaysia, Amazonia to Albania.

The sustainability of life on earth depends upon the continued ability of the air, the water and the soil to support it. These are the basic life-support systems of the planet. Of the three, the soil is probably the most robust; soils generally have a relatively high ability to withstand change. However, once damaged, their resilience, that is their ability to recover from disturbance, is low. In many cases, recovery is almost impossible. The barren mountains of Greece are testament to the irreversible damage caused by deforestation over 2,000 years ago.

Erosion is the most serious example of soil degradation, as the material of which the soil has formed, the product of thousands of years of pedogenic processes, is lost. Water is the most powerful agent of erosion, but wind erosion is also very important. The ecological and human tragedy of the dust bowl in the North American prairies in the 1930s is but one example. Furthermore, it is sometimes overlooked that the first material lost as a consequence of wind erosion and indeed very often, of water erosion also, are clay-sized particles, the most reactive material in the soil. Other serious cases of soil degradation include loss of organic matter, salinsation, breakdown of soil structure, soil sealing, nutrient loss and acidification.

Forests have been managed for the purposes of soil protection as far back as the 14th century when the felling of mountain forests in Switzerland was prohibited in order to prevent avalanches and landslides. The development of scientific forestry in the German, French and Austrian forestry schools in the late 18th and early 19th centuries led to the concept of sustainable forest yield management. This was based on the assumption that the productivity of the forest could be sustained indefinitely. It implicitly recognised the importance of the site and specifically the soil and the need to protect it.

Although the processes which give rise to soil degradation are, with the exception of sealing, natural, human impact increases, exponentially in many cases, the rate at which they occur. It is through an understanding of these processes and the how our actions influence them that we can learn to manage our soils in a sustainable manner.

The publication of the proceedings of this workshop represents a timely reminder of the risk of soil degradation in planted forests. Planted forests are by no means the most vulnerable of forests to degradation, but they do present specific problems related to the intensity of management, a sharp focus on commercial profitability, the widespread use of clearfelling and the use of relatively intensive soil cultivation measures for reforestation. The experience from the regions represented at the workshop highlight the need for a concerted approach to the protection of forest plantation soils in Europe

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Context

Ander Arias González and **Nahia Gartzia Bengoetxea**

It is difficult to estimate the cost of soil degradation due to the lack of quantitative and qualitative data. Several studies point to significant annual costs to society. Erosion, organic matter decline, salinisation, landslides and contamination might be costing up to 38 billion euro annually. As the cost of other risks like soil sealing or soil biodiversity loss are incalculable, the real cost of soil degradation is likely to greatly exceed this estimate. The majority of these costs are borne by society.

Forests, when sustainably managed, can have a central role in preventing soil degradation. The ability of forests to limit natural processes of degradation and in particular, erosion, are well established. In general, forest soils have low and infrequent levels of disturbance, particularly under continuous cover management systems and they can provide multiple ecosystem services such as carbon storage, growing medium for trees, climate change mitigation and adaptation, recreation etc. However, it is also recognised that degradation can be a serious problem in forest soils. This is most serious in conditions of unregulated exploitation, but intensively managed forests are also at risk. Management systems driven by short-term cost efficiencies may result in serious damage to soil. It is often not recognised that ecosystem management and specifically soil management is an integral part of sound forest management.

Increasing population growth and demand for wood and fibres in addition to the increasing concurrence in global markets are exacerbating the pressure on forest ecosystems. This is usually accompanied by forest management intensification and forestry management activities which can sometimes exacerbate soil degradation processes. Derived from this intensification the following risks may arise: Nutrient depletion, mainly in oligotrophic sites, can be a problem, particularly when whole tree harvesting, or stump removal are practised. Stump removal may also create disturbance-gaps, increasing the risk of erosion and nutrient loss. Machine traffic during forest operations on vulnerable soils, can result in accelerated erosion, increased loss of sediments to water courses, reduction of soil carbon stocks and increased soil compaction.

Soil degradation has trans-boundary consequences and as such, the European Commission adopted the objective to protect soils across the EU explaining why further action is needed to ensure a high level of soil protection and what kind of measures must be taken in front of the degradation risk.

A workshop was organised under the FORRISK project (FORRISK: a network for innovation in silviculture and integrated systems for forest risk management) with the aim of raising awareness of the impact of forestry practices on soil degradation and on the importance of forest soils for forest productivity. The causes of degradation were examined and the impact on long-term productivity discussed. National and regional practices and policies for soil protection were reviewed and a common framework for the reduction of the risk of soil degradation in planted forests proposed.

Overview of soil degradation risks in the EU

Soil degradation risks and prevention in the EU: Soil Protection Policy in Europe

Luca Montanarella

Introduction

Soil is a natural medium composed of mineral particles, organic matter, water, air and living organisms. It is essentially a non-renewable resource that performs many vital functions: production of food and other biomass, storage, filtration and transformation of numerous substances, including water, carbon, nitrogen and other key nutrients. As a result of human activities and natural disasters, soil degradation is accelerating in many areas, with negative effects on human health, natural ecosystems, climate change and the economy.

Soil processes underpin several economic activities (such as agriculture, energy production and construction), environmental services (e.g. flood protection and biodiversity) and many cultural activities (e.g. tourism, leisure). Despite these fundamental roles, soil degradation generally goes unnoticed; land management, which is the main pressure on the soil resource, is becoming an ever greater challenge in the EU and beyond.

Against this background, in 2006 the European Commission proposed a comprehensive strategy to protect soils in Europe and to ensure that this non-renewable natural resource will also be available for future generations. The strategy[1], entitled the "Thematic Strategy for Soil Protection", is based on four main pillars of action: legislation (a Soil Framework Directive), integration of soil protection within other EU policies (Common Agricultural Policy, Water policy, Climate policy, Nature protection, etc…), research, and awareness-raising activities. A necessary pre-condition for developing and implementing such a strategy is the availability of solid and reliable knowledge of European and global soil resources.

A full assessment of soil resources available at European and global scales, and the pressures acting on them, is therefore essential. Through the establishment of the European Soil Data Centre[2] and the European

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[1] COM(2006)231

[2] http://esdac.jrc.ec.europa.eu/

Soil Portal[3], the Joint Research Centre (JRC) provides a single focal point for collecting up-to-date soil data and information for the European Commission and EU Member States.

Soil data and information sharing

Soil data and information play a crucial role in the development and implementation of EU policies and global multilateral agreements. The JRC provides assessments of available soil resources at the global scale and acts as a single focal point for collecting soil data and information concerning climate change, biodiversity and desertification for use by the Commission and others. The JRC also helps the EU Member States to fulfil their assessment obligations regarding their soil resources. The JRC uses advanced modelling techniques, indicators and scenario analyses to provide soil information to end users in relation to the major threats to soil, identified in the EU Thematic Strategy for Soil Protection: erosion, decline of organic matter, compaction, salinisation, landslides, sealing, contamination and loss of soil biodiversity.

Soil erosion

Soil erosion is a natural process that occurs over geological time and is essential for soil formation. Concerns have arisen as to how erosion is accelerating, mostly as a result of human activity, including land use and farming practices, but also as a result of climate change. By removing the most fertile topsoil, erosion reduces soil productivity, and in shallow soils this may lead to irreversible loss of natural farmland. The JRC uses modelling techniques to assess the state of soil erosion at the European level and provides estimates of the overall costs attributable to erosion under present and likely future conditions. The JRCA has recently constructed a new model of soil erosion and has estimated the surface area affected in EU-27 to be 1.3 million km² (see Figure 1). Almost 20% of this area is subjected to soil loss in excess of 10 t/ha/y. Erosion is not only a serious problem for soil functions (estimated to cost €53 million per year in the United Kingdom alone[4]); it also has an impact on the quality of freshwater, as it transfers nutrients and pesticides to water bodies. For example, loss of phosphorus due to agricultural activities exceeds 0.1 kg/ha/y across much of Europe, but reaches levels in excess of 1.0 kg/ha/y in hotspots[5]. Addressing erosion will thus be a key contribution to achieving EU water objectives. Soil erosion is particularly intensive in areas where forest fires occur, estimated at 500,000 ha/y by the European Forest Fire Information System (EFFIS)[6].

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[3] http://eusoils.jrc.ec.europa.eu/

[4] Safeguarding our Soils. A Strategy for England, DEFRA, 2009, p. 11.

[5] http://www.eea.europa.eu/soer/europe/freshwater-quality.

[6] http://effis.jrc.ec.europa.eu.

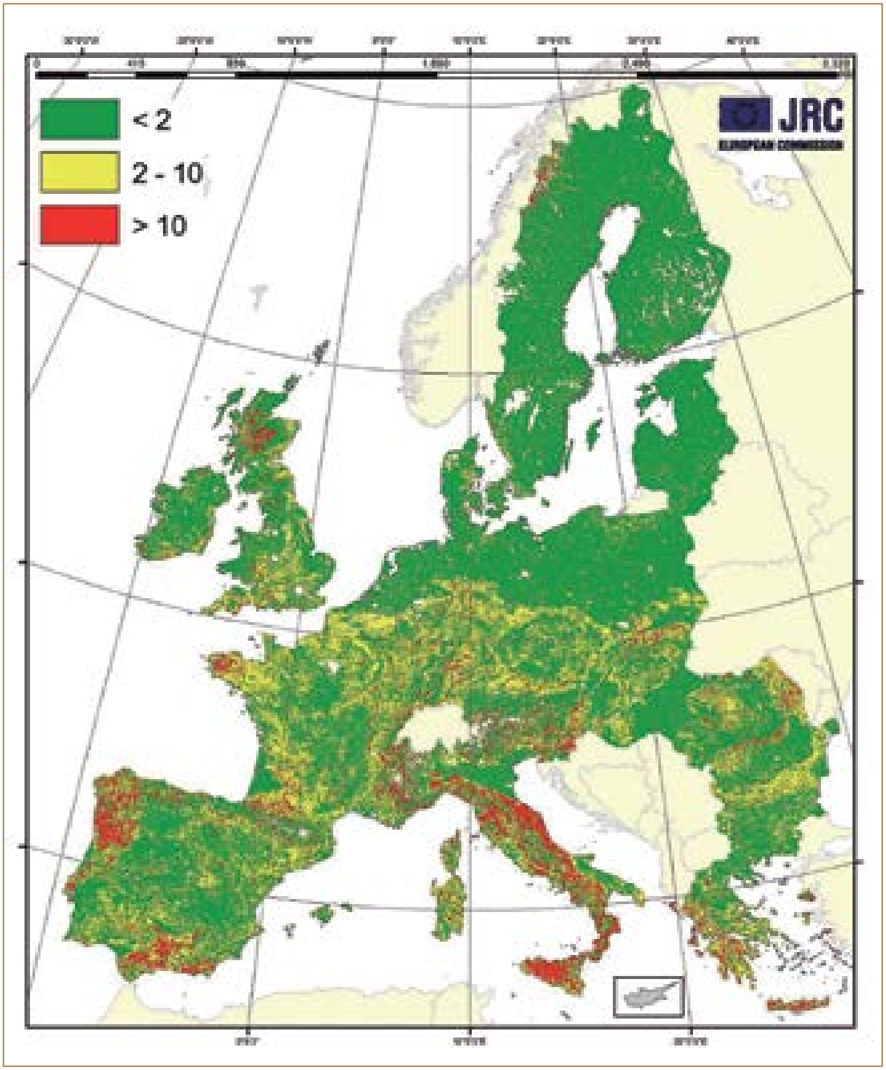

Figure 1: Soil erosion by water in the EU (t/ha/y).

Soil organic matter

Soil organic carbon is the main component of soil organic matter that improves the physical properties of soil, as it stores a large proportion of nutrients that are necessary for plant growth.

The annual rate of loss of organic matter may vary depending on natural factors (climate, soil parent material, land cover, vegetation and topography) and human activities (land use, management and degradation). The European Soil Database (scale 1:1 000 000) is one of the most homogeneous and comprehensive databases on the organic carbon/matter content of European soils. It also includes information from associated databases on land cover, climate and topography.

EU soils contain more than 70 billion tonnes of organic carbon (Figure 2), which is equivalent to almost 50 times the annual greenhouse gas emissions from the countries involved. However, intensive and continuous arable production may lead to a decline in soil organic matter. In 2009, European cropland emitted on average 0.45 tonnes of CO_2 per hectare (much of which resulted from land conversion)[7]. Conversion and use of peatland are particularly worrying. For instance, although only 8% of farmland in Germany is located on peatland, this land is responsible for about 30% of the total greenhouse gas emissions from the whole farming sector[8]. However, with appropriate management practices, soil organic matter can be maintained and even increased. Apart from peatland, particular attention should be paid to the preservation of permanent pastures and management of forest soils, as the carbon in the latter may be as old as 400-1,000 years[9]. Maintaining carbon stocks is thus essential for the fulfilment of present and future emission reduction commitments in the EU.

Soil Compaction

Soil compaction is a form of physical degradation resulting in the increased density and distortion of soil to the extent that biological activity, porosity and permeability are reduced and soil structure is partly destroyed. Compaction can reduce the water infiltration capacity and thereby increase the risk of erosion through accelerated run-off. The compaction process can be initiated by wheels, tracks, rollers or by the passage of animals. In order to define appropriate soil use and cultivation techniques, it is necessary to identify soils that are susceptible to compaction. The JRC is involved in the creation of a European map of the soil's natural susceptibility to compaction.

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[7] http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2011.

[8] http://ec.europa.eu/environment/soil/pdf/report_conf.pdf, p. 17.

[9] *Ibid.,* p. 13.

Figure 2: Distribution of organic carbon in topsoil in Europe.

Salinisation

Soil salinisation affects an estimated 1 to 3 million hectares of land in the EU, mainly in the Mediterranean countries. While naturally saline soils exist in certain parts of Europe, irrigation water —even if of high quality— includes minerals and salts that are gradually accumulated in the soil, causing salinisation. The continuing expansion of irrigation —with related problems of water scarcity and the increasing use of groundwater of marginal quality— accelerates salinisation, thereby affecting soil productivity. However, there are no systematic data available on trends across Europe.

Landslides

A landslide is the gravitational movement of a mass of rock, earth or debris down a slope and can be triggered by natural processes such as heavy or prolonged rainfall, earthquakes and rapid snowmelt, or by human activities such as the construction of roads and buildings, land use changes and irrigation. In areas affected by landslides, mainly mountainous and hilly regions, these processes are a major source of soil erosion and sediment yield to valleys and rivers, and they result in significant damage to infrastructure and property. Nowadays, population growth and expansion into landslide-prone areas increases the risk of landslides occurring in Europe. In addition, climate change is expected to lead to an increase in the number of landslides associated with extreme rainfall events in the future.

Soil sealing

Soil sealing (the permanent cover of soil with an impermeable material) and associated land take lead to the loss of important soil functions (such as water filtration and storage, and food production). Between 1990 and 2000, at least 275 hectares of soil were lost per day in the EU, amounting to 1,000 km² per year. Between 2000 and 2006, the average loss in the EU increased by 3%, but by 14% in Ireland and Cyprus, and by 15% in Spain[10]. In the period 1990-2006, 19 Member States lost a potential agricultural production capability equivalent to a total of 6.1 million tonnes of wheat, with large regional variations. This is a far from insignificant figure, given the levelling off of agricultural productivity that has already been experienced and the fact that, to compensate for the loss of one hectare of fertile land in Europe, it would be necessary to bring into use an area up to ten times larger in another part of the world[11].

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[10] http://ec.europa.eu/environment/soil/sealing.htm.

[11] C. Gardi, P. Panagos, C. Bosco and D. de Brogniez, Soil Sealing, Land Take and Food Security: Impact assessment of land take in the production of the agricultural sector in Europe, JRC, 2011 (under peer review).

Soil contamination

Soil contamination is the occurrence of pollutants, particularly man-made chemicals, in soil above a certain level, which leads to a deterioration in or loss of one or more soil functions. The chemicals most commonly involved in soil contamination are petroleum hydrocarbons, solvents, pesticides, lead and other heavy metals. The occurrence of this phenomenon is correlated with the degree of industrialisation and intensity of chemical usage. It is difficult to quantify the full extent of local soil contamination, as the vast majority of Member States lack comprehensive inventories, although this is covered by the proposed Soil Framework Directive. In 2011, according to the data received, the estimated number of potentially contaminated sites is more than 2.5 million and the number of contaminated sites identified is around 342 thousand. Municipal and industrial waste contributes most to soil contamination (38%), followed by the industrial/commercial waste (34%). Mineral oil and heavy metals are the main contaminants contributing around 60% to soil contamination. In terms of budget, the management of contaminated sites is estimated to cost around 6 billion Euros (€) annually.

Soil biodiversity

A rich soil biodiversity provides numerous essential services, including the release of nutrients in forms that can be used by plants and other organisms, purification of water by removal of contaminants and pathogens, participation in the carbon cycle, thus contributing to the composition of the atmosphere, and provision of a major source of genetic and chemical resources (e.g. antibiotics). An indicator-based map prepared by the JRC[12] (see Figure 3) shows a preliminary assessment of areas where soil biodiversity is threatened. This includes areas of high population density and/or intense agricultural activity (e.g. cereals and industrial crops, animal husbandry, greenhouses, fruit orchards, vineyards and horticulture).

Soil protection in the EU

Soil is a limited resource. European environment policy seeks to ensure its protection from contamination, erosion, loss of soil biodiversity and organic matter, which is supported by JRC's modelling expertise. In 2006, the European Commission adopted a Soil Framework Directive, which addresses soil protection, including trans-boundary aspects. The Directive aims to ensure soil productivity, especially for food production, limiting risks to human health and the environment, providing opportunities for climate mitigation and adapting and stimulating business opportunities for soil remediation.

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[12] http://eusoils.jrc.ec.europa.eu/library/maps/biodiversity_atlas/index.html, p. 62-63.

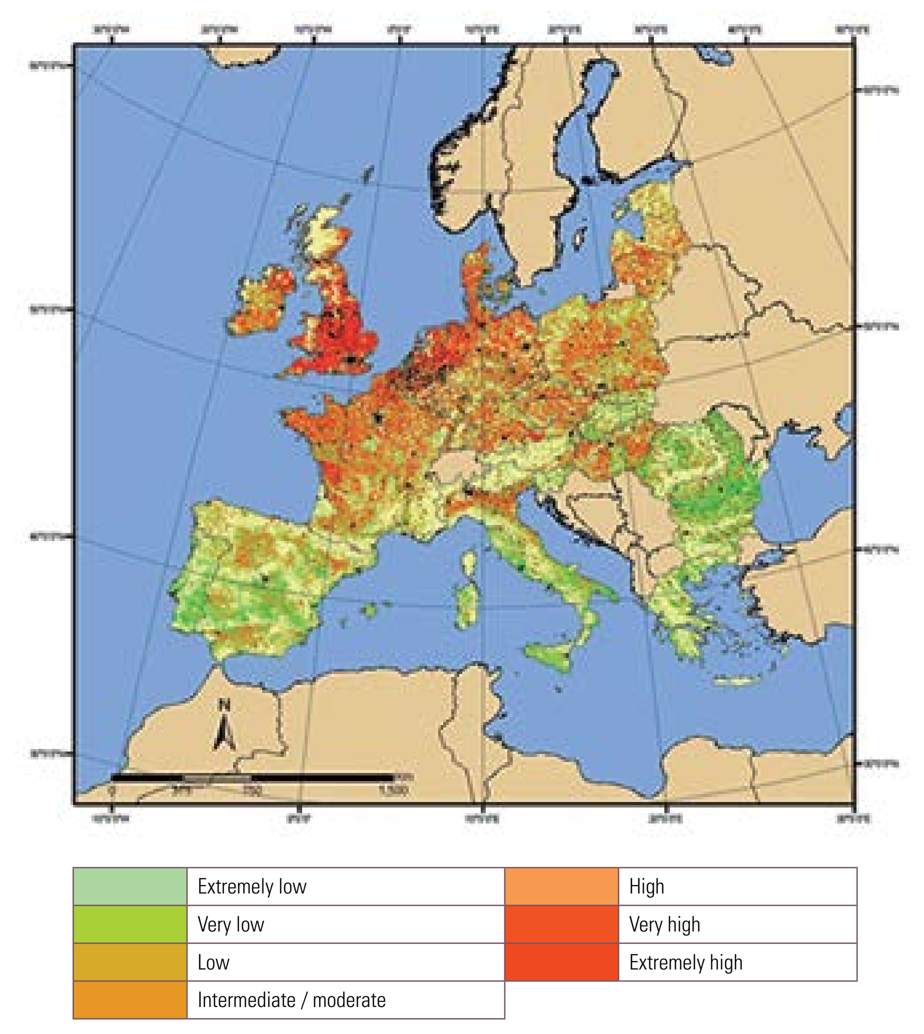

Figure 3: Potential threats to soil biodiversity.

The European Parliament adopted its opinion at first-reading of the proposal for a Soil Framework Directive on 14 November 2007; the Committee of the Regions and the Economic and Social Committee delivered their opinions on 13 February and on 25 April 2007 respectively. In Council, the proposal was repeatedly discussed but always ran into a blocking minority of 5 EU Member States (Germany, France, United Kingdom, The Netherlands and Austria).

In October 2013, the Commission adopted the Communication on "Regulatory Fitness and Performance (REFIT): Results and Next Steps"(COM(2013) 685 and its Annex) in which it noted that the proposal for a Soil Framework Directive had been pending for eight years, during which no effective action has arisen. The Commission will therefore examine carefully whether the objective of the proposal, to which the Commission remains committed, would be best served by maintaining the proposal or by withdrawing it, thus opening the way for an alternative initiative in the next mandate. This would have been judged on the feasibility of reaching adoption before the European Parliament elections of May 2014.

A possible way forward on soil protection at the EU level was discussed over lunch during the Environment Council meeting under Greek Presidency on 3 March 2014. The debate indicated that protecting soils remained an important objective for the Union, despite the fact that, in its present format, the proposal for a Soil Framework Directive could not be agreed on by a qualified majority.

In light of the above, on 30 April 2014 the Commission took the decision to withdraw the proposal for a Soil Framework Directive. This decision entered into force on 21 May 2014 upon publication on the Official Journal. In taking its decision, the Commission stated that it remains committed to the objective of the protection of soil and will examine options on how to best achieve this. Any further initiative in this respect will however have to be considered by the Commission, to take office on 1 November 2014.

Raising awareness about soil

The Soil Thematic Strategy draws attention to the lack of public awareness about the importance of soil and the need to improve knowledge sharing on best practices to fill this gap. The JRC's European Soil Bureau Network (ESBN) has established a Working Group on Public Awareness and Educational Initiatives for Soil. This group, together with other partners such as the European Land and Soil Alliance, aims to improve this situation through measures targeted at key sectors (policy makers, the general public, education, land managers, etc.).

The JRC reviews current soil education and awareness-raising programmes and how accessible these are to the general public. It has developed a multilingual resource base of publicly available educational material on the role of soils in society. JRC activities also include the coordination, promotion and provision of support materials for soil awareness activities across Europe, through events, campaigns, workshops with partners, organisation of school visits and Soil Surveys to provide specific training to young researchers. The decision of the UN General Assembly to establish a World Soil Day (5th December) and an UN International Year of Soils in 2015[13] will provide further impetus to all existing and future soil awareness initiatives. A large number of initiatives have already been announced for 2015 and will also include a series of events in Europe, especially in conjunction with the World EXPO 2015 in Milan, Italy.

Conclusions

Europe is increasingly affected by soil degradation processes. These are particularly driven by the increased pressure from urbanization and housing, as well as industrial activities. Although a coherent soil protection policy for the EU is still lacking, this will have to be addressed in the near future if we want to protect the limited soil resources of Europe for future generations. Soil protection is a pressing issue at both European and global levels. Planetary boundaries limit the availability of fertile soils for the growing population. If we do not take urgent measures to protect these limited resources, in the near future we will experience a series of serious conflicts for the control of the fertile soil resources of the globe. A common global strategy for sustainable soil management must be developed. The first steps towards such a strategy have been put in place by the FAO through the newly established Global Soil Partnership (GSP). The implementation of the proposed five plans of action of the GSP (sustainable soil management, soil awareness and education, soil research, soil data and information, standardization of measurements) will certainly open the way for effective soil management for the future. In Europe, the regional soil partnership for Europe will be the GSP component that will ensure full implementation of the proposed measures at regional scale and will contribute to the new initiatives towards a common EU soil protection policy.

References

Luca Montanarella, Ronald Vargas, Global governance of soil resources as a necessary condition for sustainable development, Current Opinion in Environmental Sustainability, Volume 4, Issue 5, November 2012, Pages 559-564, ISSN 1877-3435, http://dx.doi.org/10.1016/j.cosust.2012.06.007.

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[13] http://www.fao.org/globalsoilpartnership/news-events-archive/news/detail/it/c/239950/

Institutional tools for risk management: the case of soil degradation management

Sara Fermet-Quinet and Christophe Orazio

Cultivated forests usually require specific types of site preparation that are not common in other types of forest, e.g. forest cleaning operations (to facilitate access and planting in the case of even aged stands), stump removal, residue management, tillage to improve growth (nutrient availability and water competition), road construction (by harvesting machines) and fertilisation to increase the productivity of poor soils.

For each management option, a range of technical options that have different impacts on soil are available: use of brush cutters or shredders, ploughing slopes (which removes a large part of the soil), creation of roads (including water flow management), and use of heavy machinery on loamy soils. However, it is often the specific technique used that causes the problem rather than the practice chosen. Forest soils are exposed to many risks, including rain erosion, wind erosion, loss of organic matter (which affects the cation exchange capacity and water capacity), compaction due to the use of heavy machinery, and nutrient loss due to intensive export. All of these risks threaten the sustainability of production.

An analysis of the risks associated with soil management was conducted within the FORRISK project. The main challenges were to identify the risks and to promote the best risk management practices.

Background

The FORRISK project partners worked together on what is referred to as a “cross-cutting task” aimed at proposing improvements to risk management. This was achieved by analysis and comparison of the existing institutions and tools (procedures, guidelines, networking activities, etc.) in the FORRISK regions. Different risk management systems were first analysed risk by risk in all regions, and the systems were then analysed region by region for all the risks. On completion of this exercise, improvements to risk management systems both within and across the regions were proposed and recommendations regarding individual or multiple risks were made.

Method

RISK

- Forest fire
- Pests and diseases
- Extreme weather and climate events (storms, drought, frost)
- Game
- Soil degradation

AREA

France
- Aquitaine
- Midi-Pyrénées

Spain
- Basque country
- Asturias
- Galicia

Portugal
- Vale do Sousa

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Association for the administrative boundaries.

① Aquitaine ② Midi-Pyrénées ③ Galice
④ Asturies ⑤ Pays Basque ⑥ Vale do Sousa

The exercise was divided into three main steps:

- Step 1:

  Inventory and analysis of the existing tools for risk management, risk anticipation and risk monitoring were carried out in each region. Researchers noted the efficiency of the tools and whether or not a multirisk approach was used.

- Step 2:

  The existing tools in the regions under study were compared.

- Step 3:

  From the information acquired in steps 1 and 2, suggestions for the improvement of risk management tools in southwestern Europe were made, and ways in which the different regions could cooperate were identified.

To ensure standardisation of the data obtained, an inventory chart was used to collect the same data in each region where possible (some data were not available in all regions):

Information collected	Objective
Risk background	To understand the choices and strategies of risk management in each region in order to be able to propose regional improvements
Risk development and climate change	
Legislation concerning the risk	
Overview of risk management organisations and their main actions	To gain an overview of the general systems involved in risk management
Detailed information about the risk management organisations	To improve knowledge about the entities comprising the risk management systems
SWOT analysis of the overall system of risk management	To gain an overview of strengths, weaknesses, opportunities and threats associated with the risk management systems
Diagram of stakeholder relationships	To gain an overview of the risk management strategy in terms of geographic location and risk protection

Table 1: Summary of the inventory chart

The information was collected by the project partners in each region: EFIATLANTIC (Aquitaine, Midi-Pyrénées), NEIKER & HAZI (Basque Country), CETEMAS (Asturias), ISA (Vale do Sousa), TRAGSA (Galicia), CNPF (Midi-Pyrénées).

Results: the case of soil degradation

The complete results of the inventory and the full list of recommendations for risk management are available on the FORRISK website. The results of the analysis of soil degradation risks are summarised in the following table.

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>Forest certification:
The positive economic impact of forest certification may encourage forest owners and contractors to participate in the network and thus follow the requirements of the PEFC regarding limitation of impacts on soils
Mapping tools:
Identification of priority areas to help policy makers in their decisions
<i>Registry of forest contractors:</i> (i.e. the province of Gipuzkoa in the Basque Country)
The Forest Service in this province conducts soil damage assessments. If significant soil damage is noted, the forest contractors responsible may lose their right to operate in the province.</td><td><i>Few scientific studies</i> of soil quality loss (and productivity loss) caused by forest operations, resulting in a <i>poor perception of the risk</i> of soil degradation by forest owners and contractors</td></tr>
<tr><th>Opportunities</th><th>Threats</th></tr>
<tr><td>Improving knowledge:
Better knowledge of the impact of forest practice on soil quality and the impact of soil quality loss on forest production.
<i>Promoting and developing the use of activities and material with less impact on soils</i> (i.e. cable logging, etc.). Promotion could be done via PES (payment of environmental services).
Soil quality monitoring</td><td><i>Soil quality loss is usually irreversible</i> and when reversible is very expensive to remedy
<i>Short rotation production and residue export:</i> this type of production puts greater pressure on soils, which seldom match forest soils (usually poorer than agricultural soils). The bare soil that is common in such forest plots is more vulnerable to erosion.</td></tr>
<tr><td colspan="2">The threats, pressures and risks of soil degradation must be identified in relation to forest management. Tools that may be useful for policy makers include a method of mapping areas identified as being sensitive to soil degradation (as proposed by the JRC, European Union) and a method of mapping the potential erosion risks (as proposed by the FORSEE project). Use of these tools would increase awareness of this risk, promote the application of sustainable forestry practices and encourage activities with less impact on soil (e.g. cable logging). Management of sensitive soils must be regulated by eliminating unsustainable practices, and incentives in the form of subsidies provided to ensure that sustainable practices are carried out (e.g. Payments for Environmental Services [PES] and incentives offered in exchange for an ecological service).</td></tr>
</table>

More results and information available at http://forrisk.efiatlantic.efi.int/

Regional soil degradation risks and prevention programmes through the European planted forests

Regional soil degradation risks and prevention programmes - Iceland

Þröstur Eysteinsson

Abstract

The widespread occurrence of soil erosion and degradation in Iceland is the result of deforestation and of 1100 years of sheep grazing. Iceland has a century's worth of experience in the protection and regeneration of native birchwoods, plantation forestry, control of encroaching sand, and revegetation of land by various means. Growing more forests is obviously a large part of the solution to soil erosion and degradation. However, in addition to financial constraints, several cultural hindrances preclude large scale afforestation or revegetation. Despite the availability of knowledge and tools to remedy the situation, Iceland is likely to remain largely desertified and almost completely treeless for the foreseeable future.

Introduction

Iceland suffers severe soil erosion. A countrywide survey carried out in the mid 1990s indicated that only about 4% of Iceland was free of soil erosion and another 7% suffered only slight erosion. Subtracting the 23% of Iceland where soil is not present or erosion is not an issue for other reasons (inland waters, glaciers, recent lavas, mountain peaks, etc.) reveals that about 66% of Iceland suffers moderate to severe soil erosion (Arnalds *et al*. 2001). Because of the extent of soil erosion, Icelanders in general and people involved in the various aspects of land management in particular are very aware of the problem. There is also a good understanding of the root causes and mechanisms of soil erosion in Iceland. On the other hand, there are those who, for one reason or another (e.g. grazing interests), deny the seriousness of the problem or even view eroded land as having its own special kind of beauty and its own biodiversity (albeit impoverished) and that it should therefore be protected (Eysteinsson and Curl 2007).

In Iceland, afforestation is seen as a solution to soil erosion. Site preparation, harvesting and construction of roads can all lead to erosion or soil degradation if not done properly. However, in Iceland the erosion caused by these operations is slight in comparison with erosion stemming from other causes. Nevertheless, foresters are keenly aware of these potential problems and actively deal with them.

This paper presents a short overview of soil erosion in Iceland, largely based on the publication Soil Erosion in Iceland (Arnalds *et al.* 2001), followed by a synopsis of ways used to reduce it. Finally, some cultural hindrances to preventing soil erosion and the role of forestry are discussed.

Types, causes and magnitude

The most obvious phenomenon experienced in Iceland in relation to soil erosion is blowing sand/soil/tephra. As the country is an island with central highlands, the windward side is always wet and the leeward side always dry, regardless of the wind direction. Thus, storms that bring rain or snow to one part of the country often become dust or sand storms on the other side. Since there is no predominant wind direction, all parts of Iceland can experience dry conditions leading to wind erosion or wet conditions leading to water erosion. Sand/dust storms are frequent in disturbance-prone areas such as glacial outwash sands, and areas of encroaching sand are often found around the edges of such areas. Smaller areas of encroaching volcanic tephra are found around some volcanoes. Although areas of encroaching sand/tephra are not as extensive as some other erosional phenomena, they are active erosion fronts that destroy vegetation. Once the vegetation is inundated by sand and thus killed, the soil and sand are blown away leaving behind barren land (Eysteinsson 1994). This type of erosion has gradually created very large desertified areas, which add to the problem since eroded material continues to be blown from these and added to the encroaching fronts.

As a result of long-term sheep grazing, the most widespread type of vegetation cover in Iceland is heathland, which is largely dominated by ericaceous species (National Land Survey of Iceland 2008). This type of vegetation almost always includes at least some erosion spots (Arnalds *et al.* 2001). These are spots of exposed soil, each from less than one to a few square meters in area. They form on the tops of hummocks where the vegetation has died, often as a result of exposure to blowing snow during winter. Once the soil is exposed, winter freeze-thaw cycles (frost-heaving) prevent establishment of seedlings, and the bare spots tend to grow slowly over many years or decades. If grazing is reduced or excluded, the spots may "heal" by chance establishment of seedlings or mat-forming plants encroaching into them. In the presence of continued grazing, which is most often the case, erosion spots can grow together, eventually forming ever larger barren areas, usually with erosion escarpments at their edges. Once such escarpments form, wind and water take over as the main erosive forces and the barren areas increase even more rapidly in size eventually being eroded down to basement material, usually glacial till. This process is often so insidiously slow that changes are not obvious. However, it takes place over very large areas and is therefore a very real problem.

Another instance of large scale erosion is downslope creep caused by solifluction. Soil on steep slopes freezes and thaws in winter and tends to creep downhill, unless the vegetation is strong enough (i.e. forest vegetation) to anchor it and accumulate snow. As temperatures fluctuate above and below freezing throughout winter, continuous snow cover does not usually last for long. Thus the Icelandic climate, in conjunction with sheep grazing, is conducive to relatively rapid downslope creep, eventually leaving steep slopes largely denuded.

Other types of soil erosion are much smaller in scale. These include gully erosion during heavy rain events and during rapid snow melt (usually in spring but which can in fact take place at any time during winter and spring), stream bank erosion caused by floods, shoreline erosion around man-made reservoirs, occasional landslides and so on (Arnalds *et al*. 2001). Erosion associated with forestry is almost non-existent.

Land Use

Although the proximal causes of soil erosion in Iceland are wind, water and solifluction, in conjunction with erodible volcanic soils and a maritime-boreal climate where vegetation recovers slowly from disturbance, the ultimate cause is almost always land use. A short history of land use is needed to set the stage.

At the time of settlement in the late ninth century, the Icelandic lowlands were largely wooded. Birch forest in valleys and hillsides graded to lower-growing birch and willow woodland at higher elevations, in wetter areas and in the more exposed coastal areas. The highlands supported willow, moss and lichen tundra up to an unknown and variable elevation, above which non-continuous vegetation or "arctic desert" occurred. This elevation was not the same in all parts of the Icelandic highlands and probably fluctuated with climate change, reaching higher levels during warming periods and receding during periods of cooling. This ecotone was therefore an area of erosion during cooling periods and was probably very sensitive to disturbance (McGovern *et al*. 2007).

As in most other lands where humans settle, the first order of business was to clear forests and woodlands around the settlements to create hay fields and grazing areas for livestock. The settlers were also quick to discover that the highland tundra made for good summer grazing for sheep (McGovern *et al*. 2007). The Icelandic woodlands consisted only of downy birch *(Betula pubescens),* rowan *(Sorbus aucuparia)* and willows (principally *Salix phylicifolia* and *S. lanata*), all of which regenerate readily by stump sprouts and seeding. But they are all also palatable to livestock, meaning that moderate grazing is sufficient to prevent regeneration of woodland. It is this prevention of regeneration and not felling *per se* that was the cause of permanent deforestation. Deforestation was rapid. By the time the Icelandic sagas were being written in the 12th century, forests were often written about in the past tense (Eysteinsson and Blöndal 2000).

Disturbance caused by grazing was probably even more pronounced in the highlands, leading to a rapid increase in wind-derived erosion, as witnessed by increased aeolian deposition in the lowlands directly following settlement. The tundra-arctic desert ecotone (i.e. the front separating continuous from non-continuous vegetation), which may already have been receding due to a cooling climate, seems to have eroded very rapidly, resulting in the barren landscape that predominates at higher elevations today (Greipsson 2012).

Through the centuries, woodlands were felled in ever more remote areas, sheep became the dominant livestock and soil erosion became ever more severe, although with some fluctuations caused by periodic reductions in the human (and therefore livestock) population (McGovern *et al*. 2007). By 1950, woodland cover had decreased to less than 1% of Iceland's land area, from as much as 40% at settlement (Bjarnason 1974), and continuous vegetation/soil cover had decreased to less than 25% (from about 65% at settlement) (Arnalds 1988). In other words, it is estimated that about 95% of Iceland's original forests and about 60% of Iceland's vegetation/soil cover has been lost in the last 1140 years. Only a small part of the soil erosion in highland areas and none of the deforestation are attributable to climate change (the "little ice age"). In the lowlands, much of the erosion is associated with permanent deforestation and both are ultimately the result of sheep grazing.

Remedies

Icelanders have been actively dealing with soil erosion and preventing further deforestation since 1907. Originally combined in a single agency, forestry and soil conservation went their separate ways in 1916 for political reasons. This split still negatively affects cooperation between the different agencies. In forestry, emphasis was initially placed on protecting woodland remnants. Beginning in the 1950s, afforestation of treeless (but not eroded) land became the main emphasis, and afforestation with the specific aim of reclaiming eroded land commenced in 1990. Regarding soil conservation, the main effort was on controlling encroaching sand for most of the last century, with reclamation of eroded areas also emphasized since the 1970s. These efforts, in both forestry and soil conservation, require fencing to exclude sheep (Blöndal and Gunnarsson 1999).

Fencing of woodland remnants resulted in regeneration, and many birchwoods existing today were saved from complete destruction in this way. Afforestation, with several exotic tree species as well as the native birch, was so successful that today there is a fledgling forest industry in Iceland (Eysteinsson 2014). Areas of encroaching sand were fenced and lyme grass *(Leymus arenarius)* was sown, thus forming dune areas and greatly retarding further encroachment. Reclamation of eroded areas has been successful in many areas, especially where the Nootka lupine *(Lupinus nootkatensis)* has been planted. Sowing grass seed or simply spreading fertilizer to strengthen the natural vegetation has resulted in succession towards continuous vegetation in some cases. However, this is often a temporary solution, i.e. if not followed by repeated application of fertilizer or planting of trees.

In short, Icelanders have over a century's worth of experience and a variety of tools to use in the struggle against soil erosion. Nevertheless, Iceland is still largely a man-made desert, is still almost completely treeless and severe erosion still exists.

Cultural obstacles

People do not readily change the way they do things and are particularly conservative when it comes to how they make their living. In a recent study, Lidskog and Sjödin (2014) examined the reactions of forest owners in southern Sweden in the aftermath of the storm "Gudrun", which blew down large swathes of forest in 2005. Forest researchers found that it was mostly Norway spruce that was blown down and suggested planting a more diverse mix of species to better tolerate future storms. The state heeded this advice and offered grants for planting species other than Norway spruce. However, the forest owners mainly replanted with Norway spruce. Why? The reason was that they knew how to grow Norway spruce and knew the market for Norway spruce timber. They were much less certain about other species and considered the associated risk to their livelihood of planting them to be greater than the risk from future storms. Evidently it takes more than pointing out a problem and suggesting solutions for people to change the way they do things. It also often takes more than financial incentives (state grants).

There is a tradition of free-range summer grazing of sheep in Iceland. In some cases, this simply entails releasing the sheep outside the home fields and in other cases transporting them long distances to summer pastures in the highlands. Thus, in the summer, sheep can be found anywhere that is not fenced to keep them out. Despite research indicating both the seriousness of Iceland's erosion problems and their connection with sheep grazing, there has been a great deal of resistance to changing this pattern of land use. There has also not been any political willingness to promote such change (Arnalds and Barkarson 2003). Both afforestation and soil conservation efforts will therefore continue to be restricted to relatively small areas in the foreseeable future.

A more recent cultural issue involves the denial by some groups of the fact that lack of forest cover and soil erosion are problems (Eysteinsson and Curl 2007). To paraphrase: the treeless landscape offers unhindered vistas, desertified areas are home to interesting lichens and small alpine flowers; a treeless, eroded landscape is what we grew up with, it is what is special about Iceland and we don't want it to change. To some people, such things are more important than productivity, ecosystem function or loss of vegetation due to ongoing erosion. Such attitudes are commonly held by people in the tourism business, for the same reason that Swedish forest owners want to stick with Norway spruce and Icelandic sheep farmers want to continue with free-range grazing. It is perhaps more surprising that many nature conservationists deny the seriousness of these problems, placing emphasis on maintaining the biodiversity *status quo,* advising against use of exotic species as a means of achieving afforestation or soil conservation goals. Thus, the tendency among nature conservationists is to want to preserve the *status quo,* regardless of how it got that way or the long term consequences. Particularly, there is a tendency to repeat the current anti-exotics dogma within the biodiversity discourse, which hinders soil conservation and afforestation efforts in Iceland.

Soil erosion and forestry

In Iceland we see forestry as a solution to soil erosion/degradation and not as a cause of such problems. The Icelandic forestry sector would in fact like to see afforestation used much more widely in erosion control. Planting trees in dune areas is a logical next step after lyme grass has stabilised the sand, rather than letting sheep graze on the lyme grass. Afforestation of degraded grazing land quickly heals erosion spots, and afforestation of hillsides stops solifluction creep. Larch, pine and poplar can be grown for timber production in desertified areas, especially with nitrogen input from lupines, thereby turning essentially worthless land into productive forest and reinitiating soil formation. Strategic afforestation can be used to sequester volcanic ash. Future erosion problems resulting from management or utilisation of the forests are likely to be small in comparison with the problems that afforestation can potentially solve. Any such problems are also likely to be dealt with because Icelandic foresters are very aware of the problem of soil erosion.

Forestry in Iceland is small in scale, as is effective and permanent erosion control by other means. Because of prevailing land use and public attitudes, it seems unlikely that the situation will change much in the foreseeable future. Over most of Iceland, sand and soil will continue to blow from deserts, erosion spots will continue to grow and soil will continue to creep downslope. The short term interests of sheep farmers, the tourism business and *status quo* conservationists are not in danger from forestry or soil conservation. Ultimately, however, the current predominant land use is unsustainable and the desire to preserve a degraded and eroded landscape for the sake of tourism or to maintain the impoverished state of biodiversity that exists there is inexcusable. We humans make demands of the ecosystems around us. We demand that they provide us with food, other material goods and a host of services. To provide them over the long term, the ecosystems must be robust and resilient, which means that we often have to maintain them and sometimes change them.

References

Arnalds, A. 1988. Landgræðsla á Íslandi fyrr og nú (Soil conservation in Iceland past and present). In A. Arnalds (ed.) Græðum Ísland; Landgræðslan 80 ára (Heal Iceland; the Soil Conservation Service aged 80). Iceland Soil Conservation Service. 236 pp. In Icelandic.

Arnalds, O., E.F.Thorarinsdottir, S. Metusalemsson, A. Jonsson, E. Gretarsson and A. Arnason. 2001. Soil erosion in Iceland. Soil Conservation Service,

Agricultural Research Institute. Reykjavik. 121 pp.

Arnalds, O., and B.H. Barkarson. 2003. Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. Environmental Science and Policy 6: 105-113.

Bjarnason, H. 1974. Athugasemdir viðk sögu Íslands í sambandi við eyðingu skóga (Comments on Icelandic history with respect to deforestation – in Icelandic with English summary). Icelandic Forestry 1974: 30-43

Blöndal, S., and S.B. Gunnarsson. 1999. Íslandsskógar: Hundrað ára saga (Iceland's forests: a hundred year history). Mál og Mynd. Reykjavík: 267 pp.

Greipsson, S. 2012. Catastrophic soil erosion in Iceland: Impact of long-term climate change, compounded natural disturbances and human driven land-use changes. Catena 98: 41-54.

Eysteinsson, T. 1994. Áfoksgeiri við Kringlutjörn (Aeolian deposition event at Kringlutjörn). Græðum Ísland V (Soil Conservation Service yearbook V): 135-141.

Eysteinsson, T. 2014. Staða og þróun viðarsölu Skógræktar ríkisins 2013 (Status and development of wood sales by the Iceland Forest Service 2013). Iceland Forest Service annual report for 2013: 34-38.

Eysteinsson, T., and S. Blöndal. 2000. The forests of Iceland at the time of settlement: Their utilisation and eventual fate. In S. Lewis-Simpson (ed.) Vinland Revisited: The Norse World at the Turn of the First Millenium, Selected papers from the Viking Millenium International Symposium Sept. 15-24, 2000. Newfoundland and Labrador, Canada. St. John's, Historic Sites Association of Newfoundland and Labrador Inc.: 411-416.

Eysteinsson, T., and S. Curl. 2007. Strange ideas; subjectivity and reality in attitudes towards afforestation in Iceland. In G. Halldórsson, E.S. Oddsdóttir and O. Eggertsson (eds.) Effects of afforestation on ecosystems, landscape and rural development: Proceedings of the AFFORNORD conference, Reykholt, Iceland, June 18-22, 2005. TemaNord 2007: 508: 344 pp.

Lidskog, R. and D. Sjödin. 2014. Why do forest owners fail to heed warnings? Conflicting risk evaluations made by the Swedish forest agency and forest owners. Scandinavian Journal of Forest Research 29, no. 3: 275-282.

McGovern, T.H., O. Vésteinsson, A. Friðriksson, M. Church, I. Lawson, I.A. Simpson, A. Einarsson, A. Dugmore, G. Cook, S. Perdikaris, K.J. Edwards, A.M. Thomson, W.P. Adderley, A. Newton, G. Lucas, R. Edvardsson, O. Aldred, and A. Dunbar. 2007. Landscapes of Settlement in Northern Iceland: Historical Ecology of Human Impact and Climate Fluctuation on the Millennial Scale. American Anthropologist 109, Issue 1: 27-51.

National Land Survey of Iceland. 2008. CORINE Land Cover 2006 in Iceland, final report. 53 pp.

Current and future degradation risks to forest soils in Ireland*

Kenneth A. Byrne, Julian Aherne and Thomas Cummins

Introduction

Soil and civilization are inextricably linked (Diamond 2005, Montgomery 2007) with agriculture and forestry being primary providers of food and fibre. Throughout human history the demand for this service has grown concomitantly with human population. World population at the end of 2013 was approximately 7.1 billion and is expected to peak at 9.22 billion in 2075 (United Nations 2004). To meet this increase, global food production will have to double in the next 50 years. In addition soil resources must also be managed to meet a range of other services such as combating global warming, enhancement of the quality and quantity of freshwater resources, provision of a habitat for biodiversity, reduction of desertification, provision of a repository for waste, preservation of archaeological, geological and astronomical records and respond to pressure for new energy sources (Lal 2007). Despite the numerous services that soil provides it is an unappreciated and often unsustainably managed resource. Indeed, soil degradation is one of the most serious global environmental challenges. If soils are to meet the need for increased food production and the other services they provide it will be necessary to halt the current rate of degradation and to initiate appropriate restoration measures.

This paper will describe the climate, soils and forests of Ireland before considering potential sources of soil degradation and their amelioration.

Climate and Soils of Ireland

Located in the middle latitudes, Ireland has a temperate humid climate predominantly influenced by proximity of the Atlantic Ocean and prevailing westerly winds. The North Atlantic Drift is responsible for the mild maritime effect which is most marked near the coasts. North Atlantic depressions frequently pass to the northwest of the country bringing increased rainfall, windiness and cloud cover to that region of the country compared to the southeast. This northwest – southeast gradient is distorted by altitudinal factors, nearness of the sea and a poor continental influence.

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Precipitation is highly variable across temporal and spatial scales. The average annual rainfall typically varies between 750 mm in the east and northeast to in excess of 1200 mm in the southwest, west and northwest. In mountainous areas it can exceed 1600 mm with local values as high as 3600 mm in mountainous areas along the western seaboard (Figure 1). Proximity to the sea and altitude greatly influence temperature. Typically mean annual temperature varies between 9°C and 10°C. Current climate projections suggest that winters will become wetter (up to 14%) and summers drier (up to 20%). In addition, the frequency of heavy winter precipitation could increase by 20%. Temperatures are expected to increase by about 1.5°C by mid-21st century (Gleeson 2013).

In the global context, Irish soils are relatively young having formed during the last 10,000 to 20,000 years. The complex interaction of soil forming factors has given rise to a vast array of soils which result from a multitude of pedogenic processes. Collins et al. (2004) have generalised these as follows:

a) Widespread acidification due to excessive leaching.

b) Movement/translocation of silicate clay leading to the development of clay-rich subsurface horizons.

c) Accumulation of the oxides of iron and aluminium and to a lesser extent, humus in coarse textured soils.

d) A reasonably high level of soil organic matter accumulation.

e) Development of conditions associated with wetness.

f) Biological homogenization of soil.

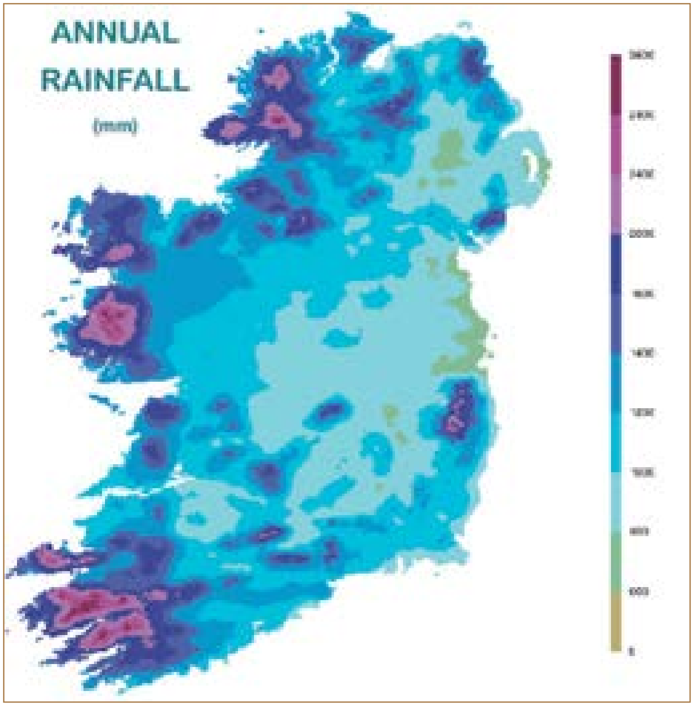

Figure 1: Mean annual rainfall in Ireland during 1981–2000 (Walsh 2012)

Forestry in Ireland

At the beginning of the 20th century the forests of Ireland had reached their lowest ebb. Centuries of exploitation had cleared the native forests and less than 1.5% of the land area was under forest. In the period since, successive government sponsored afforestation schemes have seen forest cover being restored. Although this began in the 1920's it was not until the 1950's that large scale afforestation took place. The was facilitated by the availability of (1) large areas of land (mostly blanket peatland) which could be purchased for relatively low prices and (2) the development of tracked machinery and ploughs which enabled large scale drainage of such lands. The state sector dominated afforestation until the mid-1980's and the main species planted were exotic conifers, principally Sitka spruce (*Picea sitchensis* (Bong.) Carr) and lodgepole pine (*Pinus contorta* Dougl.). Since the 1980's there has been a massive expansion in private sector afforestation as a result of state and European Union funded schemes which support not only establishment costs but also provide annual payments to compensate farmers for loss of income when agricultural land is afforested. Such schemes also favour planting with broadleaf species. The most recent National Forest Inventory (Forest Service 2012) estimated that forests (both stocked and un-stocked land) cover 731,650 ha or 10.5% of the land area. Approximately 53% of these forests are in public ownership with the balance in private ownership. Conifer forest is the dominant type accounting for 74.2% of all forests. Broadleaf forests account for 25.8%. Sitka spruce is the dominant tree species occupying 52.2% of the forest area, with pines, principally lodgeople pine, occupying 9.7% of the forest area. Broadleaf species include Ash (*Fraxinus excelsior* L.), Sessile oak (*Quercus petraea* (Mattuschka) Lieblein), Pedunculate oak (*Quercus robur* L.), Beech (*Fagus sylvatica* L.), Sycamore (*Acer pseudoplatanus* L.) and Birch spp. ((Silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.)). In general, Irish forests are relatively young with 56% of all forests being less than 20 years old.

Until the 1980s afforestation was largely confined to peat soils. However with the growth of private sector afforestation, planting of mineral soils became more prevalent. Currently 44% of forests are on peat with 56% on mineral soils (Forest Service 2012). Blanket peat is the dominant peat type with basin peat accounting for the remainder (Table 1). Gleys and podzols are dominant mineral soils accounting for 26% and 11% of the forest estate respectively (Redmond *et al.* 2007). Brown earth, brown podzolic and grey brown podzolic soils are also significant.

Soil group	Area (1000 ha)	Percent of total
Basin peat	66.88	10.7
Blanket peat	196.80	31.5
Brown earth	52.47	8.4
Brown podzolic	28.89	4.6
Gley	163.30	26.1
Grey brown podzolic	15.25	2.4
Lithosol	14.39	2.3
Podzol	66.51	10.6
Regosol	4.03	0.6
Rendzina	8.41	1.3
Cutaway peat	7.23	1.2
Sand	1.19	0.2
Limestone pavement	0.40	0.06
Total	625.75	100.0

Table 1: Total stocked forest area and percentage by soil group in Ireland (from Redmond et al. 2007).

Policy context

Ireland's forests are managed according to the principle of Sustainable Forest Management as described in the Irish National Forest Standard (Forest Service 2000a). This outlines the criteria and indicators for the implementation of Sustainable Forest Management. This is supported by the Code of Best Forest Practice (Forest Service 2000b), which describes all forest operations and the manner in which they should be carried out. In addition there are a series of environmental guidelines in relation to water quality (Forest Service 2000c), archaeology (Forest Service 2000d), landscape (Forest Service 2000e), biodiversity (Forest Service 2000f), harvesting (Forest Service 2000g), aerial fertilisation (Forest Service 2001), and forest protection (Forest Service 2002).

Forest policy has recently been reviewed and updated (Department of Agriculture, Food and the Marine 2014a) with the strategic goal *'To develop an internationally competitive and sustainable forest sector that provides a full range of economic, environmental and social benefits to society and which accords with the Forest Europe definition of sustainable forest management'.* The environmental review of this policy document (Department of Agriculture, Food and the Marine 2014b) makes frequent reference to the importance of soils for Sustainable Forest Management and highlights the need for research in support of this. Continuing policy changes will also have implications for forest soils. For example, Ireland is obliged to supply 16% of its' energy requirement from renewables by 2020. Meeting this demand will double the gross demand for wood biomass from 0.952 M m^3 in 2011 to 1.696 M m^3 in 2020 (COFORD Roundwood Demand Group, 2011).

Soil degradation risks

Loss of soil organic matter

Afforestation is widely considered to have a positive role in mitigating greenhouse gas emissions through the sequestration of atmospheric carbon in biomass and soil. Given the scale of afforestation in recent decades, Ireland is well placed to use carbon sequestration in forests to assist in meeting its' commitment to reduce GHG emissions (Byrne 2010). Studies to date on the impact of afforestation on carbon stocks in mineral soils show contrasting results. For example, Reidy and Bolger (2013) examined a chronosequence of Sitka spruce on a wet mineral gley soil and estimated that during a 47 year period 1.83 t C ha^{-1} was sequestered in the soil. Wellock *et al.* (2011) used a paired plot approach to compare soil carbon stocks in afforested to pre-afforestation land use and found no significant difference. They attributed this to the high uncertainty associated with low sample numbers. Furthermore, the study was restricted to 21 sites that covered a limited area of the country and therefore it's national scale application is limited.

In the natural state, peatlands are sinks for carbon dioxide and sources of methane. Drainage and subsequent afforestation greatly alters this balance (Minkkinen *et al.* 2008) with the lowering of the water table leading to increased organic matter decomposition and associated soil respiration. Methane emissions cease due to the lowered water table. Byrne and Farrell (2005) investigated the effect of afforestation on blanket peatland and suggested that while afforestation increased soil respiration, this could be compensated by carbon sequestration by the forest crop. In addition to changes in the GHG balance, afforestation causes other changes to peat soils (Byrne and Farrell 1997). Drainage leads to subsidence, increased bulk density and decreased porosity and hydraulic conductivity (Burke 1978). In recent decades support for peatland afforestation has fallen due to the poor economic return from these forests as well as aesthetic and environmental concerns (Renou and Farrell 2005). Furthermore, growing awareness of the ecosystem service provided by peatland ecosystems (Renou-Wilson *et al.* 2011) has stimulated interest in restoring forested peatlands to their original condition. Restoration and rewetting is widely seen as a viable means to restore the carbon sink function of peatlands (Höper *et al.* 2008). Restoration typically involves blocking of drains to raise the water table and promote peatland vegetation, and where necessary the introduction of peat forming plants (e.g. Sphagnum). Since 2002, under the EU LIFE Programme, Coillte (the Irish state forestry company) have rewetted approximately 2,500 ha of peatland forests, with a further 635 ha of forested raised bog having been rewetted in the 4th LIFE project. Furthermore, Coillte's Strategy for the Future Management of Low Production Forests (Tiernan 2008) identifies 43,000 ha of western peatland forests that it deems uneconomic and unsustainable and envisages that these areas will either be replanted with minimum inputs or restored. Tiernan (2007) estimated that 12% of Western Peatland Forests have the potential for successful restoration, equating to a total area of 12,640 ha.

Soil erosion

Irish soils are usually vegetated which helps prevent the occurrence of erosion (Favis-Mortlock 2006). Removal of vegetation, when combined with rainfall and surface water flow, presents the opportunity for erosion to occur. Studies that have been carried out in forests are restricted to peat soils and their main focus has often been on the off-site impacts (e.g. surface water quality) rather than on-site impacts. Forest soils will be most susceptible to erosion following clearfelling, and during subsequent soil preparation for reforestation, when removal of the forest cover leads to decreased evapotranspiration and an elevated water table and machine operations may expose the soil. In addition ground preparation, can expose the soil. May *et al.* (2005) investigated soil erosion and transport in a peat dominated catchment in the west of Ireland with 23% forest cover and estimated a sediment yield of 0.16 t ha^{-1} yr^{-1}. However this was not related to any specific land use. Also in the west of Ireland, Finnegan *et al.* (2014) compared suspended sediment in streamflow from two forest catchments on peat using one as a control site (no clearfelling) and the other as a study site (clearfelling). Sediment load from both catchments were similar (0.20 t ha^{-1} yr^{-1}) and while levels increased during clearfelling this was not significant. Rogers *et al.* (2011) concluded that with good harvesting practice it is possible to prevent sediment delivery to streams.

Soil compaction

Forest operations such as timber harvesting (thinning and clearfelling), site preparation and planting use heavy equipment and can take place year round. As such there is potential for rutting and compaction to occur, particularly with multiple passages of machinery. Soil disturbance and damage on sensitive sites is limited by laying a brash mat (i.e. harvesting residue of branches, tops and logs of sub-merchantable size) ahead of harvesting and extraction machinery. In a study of a thinning operation in a 30 year old Norway spruce (*Picea abies* (L.) Karst), Nugent *et al.* (2003) found that the impact of machine traffic was limited to the top 40 cm of soil. The authors suggest that damage can be mitigated by limiting the number of machine passes and by careful selection of the size and type of wheels or tracks.

Soil nutrient status

As stated above with regard to soil erosion the primary focus of studies on nutrient losses conducted to date has not been the on-site impact but rather on the off-site impacts, particularly surface waters. Peatland forests typically require application of phosphatic fertilizer to ensure crop establishment and growth (Renou-Wilson and Farrell, 2005). Using catchment based studies a number of authors have reported phosphorous losses from peatland forests after clearfelling (Cummins and Farrell, 2003; Rodgers *et al.* 2010; Finnegan 2014). The pattern of phosphorus release is similar with a rise is phosphorous concentrations in streamwater immediately following clearfelling and a second peak the following summer. These losses may be due to the absence of phosphorous uptake by a growing tree crop, site disturbance during harvesting and ground preparation or decomposition of forest litter. Among the range of possible mitigation measures are whole tree harvesting and grass seeding (Rodgers et al 2010; O'Driscoll *et al.* 2014).

Soil acidification

In regions where precipitation exceeds evapotranspiration, transport of solutes from mineral weathering leaves behind a residue of more-acid substances, dominated by aluminum, leading to soil acidification. Where this occurs, it is exacerbated by organic acids from decomposing plant material, external inputs of oxidised atmospheric sulphur (S) and nitrogen (N) compounds, and acid excretion owing to vigorous plant growth (and subsequent harvest removals). Acidification is offset by weathering of alkaline minerals, chiefly carbonates in Ireland's relatively young soils, which is the chief determinant of ecosystem susceptibility to soil acidification. Notably, upland soils, predominately located along the coastal margins of Ireland are derived from base-poor parent material such as granite and old red sandstone leading to soils with low base cation (calcium, magnesium and potassium) weathering rates (Figure 2). Forest cover in Ireland is primarily relegated to these acid-sensitive regions.

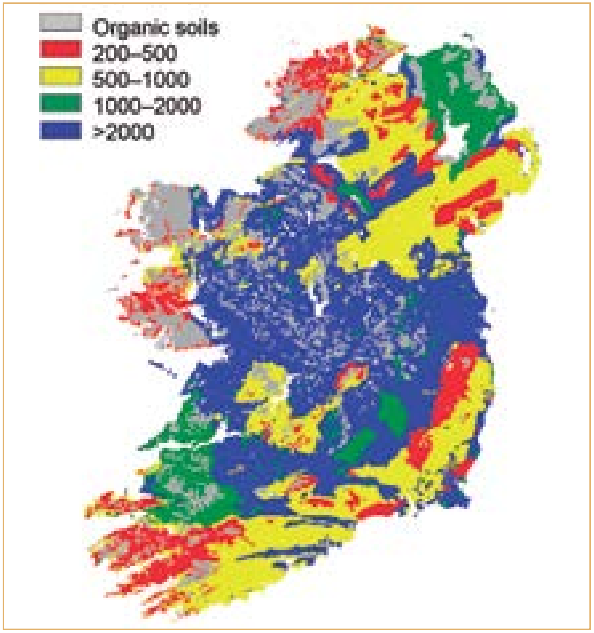

Figure 2: Soil base cation weathering rate ($mol_c\ ha^{-1}\ a^{-1}$) in Ireland (Aherne and Farrell 2002).

Atmospheric deposition of anthropogenic S and N emissions is the main external driver of soil acidification. The sensitivity of forested soils to acidic deposition is widely assessed using an effects-based indicator known as the critical load, i.e., the input of acidifying compounds below which harm will not occur according to present knowledge. Assessment of critical loads for Ireland has been carried out for free-draining mineral soils (Aherne and Farrell, 2000 and 2002a), but is of limited value for organic soils, and does not relate to farmlands, which have all been limed with calcium carbonate. Exceedance of critical loads of acidity are predicted in regions affected both by local industrial emissions and transboundary emissions borne on easterly winds (Bowman and McGettigan, 1994; Aherne and Farrell 2002b); this limits concern to eastern, central and south-central regions of Ireland (EPA 2012). A long-term forest monitoring plot (under ICP-Forests monitoring programme) located on the east coast of Ireland has shown nitrate leaching and exceedance of critical load (Farrell *et al.* 2001). However, this same site has shown a long-term increase in soil-solution pH and reduction in soil-solution sulphate concentration in response to national and international emission control regulations (Johnson *et al.,* 2013).

In addition to anthropogenic drivers, atmospheric deposition of marine ions during storm events has been shown to cause episodic acidification (Farrell, 1995; Johnson *et al.,* 2013). Extreme inputs of sodium and magnesium from marine sources can displace hydrogen or aluminum on the soil exchange complex in shallow base-poor mineral or organic soils, leading to an export of acidity to surface waters (i.e., the sea-salt effect). Climate change is predicted to increase the frequency and intensity of storms events over Ireland, leading to potential nutrient deficiencies in Irish forests on organic soils along the western coast margins.

Harvest removals

Soil acidification may also occur where the rate of base cation removal in harvested biomass is much greater than that generated through mineral weathering. In general, commercial forest plantations in Ireland produce high biomass under short rotations. Management practices such as whole tree harvest have the potential to negatively impact soil exchangeable pools of calcium and are unsustainable during the long-term (Johnson et al 2015). Recent studies suggest that acidic deposition has a relatively minor effect on soil acidity in commercial Irish forests in comparison with harvest removal of base cations (Johnson et al 2015).

Terrestrial eutrophication

Critical loads methods are also used to assess the limit of N deposition below which damage — in this case, elevated nitrate leaching, soils acidification or change in species composition towards lower diversity — will not occur. Such effects are of concern for semi-natural grasslands, heathlands, peatlands, and native woodland plant communities. In Ireland, nutrient N exceedence is primarily attributed to national ammonia emissions (which make up about 80% of N emissions); there is evidence of exceedence of critical load for nutrient N in grasslands (Henry and Aherne 2014) and native woodlands in Ireland.

Climate change

Ireland's climate is expected to change in the coming decades. These changes may have potential impacts for forest soils. For example, increased windthrow due to increased storm frequency and wetter soil conditions could have implications for forest management and lead to further disturbance of soils. While windthrow models have been developed for Irish forests (Ni Dhubhain, 1998), they need to be adapted to incorporate future climate changes scenarios. Climate change will also have implications for species selection. Black *et al.* (2010) have proposed a number of adaptive strategies including selection of new provenances or species suitable to warmer climates, planting policies should consider changes to soil water status, changes in silvicultural practices and rotation length and reduction of fire load in older stands to reduce the risk of increased fires due to drier summer conditions.

Acknowledgements

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References

Aherne, J. and Farrell, E.P. (editors) 2000. Determination and Mapping of Critical Loads for Sulphur and Nitrogen and Critical Levels for Ozone in Ireland. Final Report. R&D Report Series No. 7. Environmental Protection Agency, Ireland, 225 pp [URL: erc.epa.ie/safer/resource?id=b931d553-2076-102f-a0a4-f81fb11d7d1c].

Aherne, J. and Farrell, E.P. 2002a. Steady state critical loads of acidity for sulphur and nitrogen: a multi-receptor, multi-criterion approach. Science of the Total Environment 288:3, 183–197.

Aherne, J. and Farrell, E.P. 2002b. Deposition of sulphur, nitrogen and acidity in precipitation over Ireland: chemistry, spatial variation and long-term trends. Atmospheric Environment 36:8, 1379–1389.

Black, K., Xenakis, G. and Ray, D. 2010. Climate change impacts and adaptive strategies. Irish Forestry, 67 (1–2): 67–85.

Bowman, J.J. and McGettigan, M. 1994. Atmospheric deposition in acid-sensitive areas of Ireland – the influence of wind direction and a new coal burning electricity-generation station on precipitation quality. Water Air and Soil Pollution 75:1–2, 159–175.

Burke, W. 1978. Long-term effects of drainage and land use on some physical properties of blanket peat. Irish Journal of Agricultural Research. 17: 315–322.

Byrne, K.A. 2010. The role of plantation forestry in Ireland in the mitigation of greenhouse gas emissions. Irish Forestry, 67 (1–2), 86–96.

Byrne, K.A. and Farrell, E.P. 2005. The effect of afforestation on soil carbon dioxide emissions in blanket peatland in Ireland. Forestry, 78 (3), 217–227..

Byrne, K.A. and Farrell, E.P. 1997. The influence of forestry on blanket peatland. In Humic Substances, Peats and Sludges: Health and Environmental Aspects. M.H.B. Hayes and W.S. Wilson (eds.), The Royal Society of Chemistry, pp. 262–277.

COFORD Roundwood Demand Group. 2011. All Ireland Roundwood Demand Forecast 2011–2020. COFORD, Dublin.

Collins, J.F., Larney, F.J. and Morgan, M.A. 2004 Chapter 6: Climate and Soil Management. In Climate, Weather and Irish Agriculture. T. Keane and J.F. Collins (eds.), Agmet, Dublin, pp. 119–160.

Cummins, T. and Farrell, E.P. 2003. Biogeochemical impacts of clearfelling and reforestation on blanket peatland streams I. phosphorus. Forest Ecology and Management, 180 (1–3), 545–555.

Department of Agriculture, Food and the Marine. 2014a. Forests, products and people. Ireland's forest policy – a renewed vision. Department of Agriculture Food and the Marine, Dublin.

Department of Agriculture, Food and the Marine. 2014b. Environmental report on the forest policy review. Department of Agriculture Food and the Marine, Dublin.

Diamond, J. 2005. Collapse: how societies choose to fail or succeed? Viking: New York.

EPA 2012. Ireland's Environment 2012: An Assessment. The Irish Environmental Protection Agency. URL: www.epa.ie.

Farrell, E.P. 1995. Atmospheric deposition in maritime environments and its impact on terrestrial ecosystems. Water Air and Soil Pollution 85, 123–130.

Farrell, E.P., Aherne, J., Boyle, G.M. and Nunan, N. 2001. Long term monitoring of atmospheric deposition and the implications of ionic inputs for the sustainability of a coniferous forest ecosystem. Water, Air, and Soil Pollution, 130, 1055–1060.

Favis-Mortlock, D.T., 2006. Ireland. In: J. Boardman and J. Poesen, eds. Soil erosion in Europe. Chichester: Wiley, 455–462.

Finnegan, J., Regan, J.T., O'Connor, M., Wilson, P., Healy, M.G. 2014. Implications of applied best management practicefor peatland forest harvesting. Ecological Engineering 63, 12– 26.

Forest Service. 2000a. Irish National Forest Standard. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2000b. Code of Best Forest Practice. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2000c. Forestry and Water Quality Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2000d. Forestry and Archaeology Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2000e. Forestry and the Landscape Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2000f. Forest Biodiversity Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2000g. Forest Harvesting and the Environment Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2001. Forestry and Aerial Fertilisation Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2002. Forest Protection Guidelines. Forest Service, Department of the Marine and Natural Resources, Leeson Lane, Dublin 2.

Forest Service. 2012. The Second National Forest Inventory - Republic of Ireland - Main Findings. Forest Service, Department of Agriculture, Food and the Marine, Johnstown Castle Estate, Co. Wexford, Ireland.

Gleeson, E., McGrath R. and Treanor M. 2013. In Ireland's climate: the road ahead, Met Éireann, Dublin.

Henry, J. and Aherne, J. 2014. Nitrogen deposition and exceedance of critical loads for nutrient nitrogen in Irish grasslands. Science of the Total Environment 470–471, 216–223.

Höper, H., Augustiin, J., Cagampan, J.P., M., D., Lundin, L., Moors, E. Höper, H., Vasander, H., Waddington, J.M., Wilson, D. 2008. Restoration of peatlands and greenhouse gas balances. In Peatlands and Climate Change. M. Strack (ed.), International Peat Society and Saarijärven Offset Oy, Saarijärvi, Finland, pp. 182–210.

Johnson, J., Aherne, J. and Cummins, T. 2015. Base cation budgets under residue removal in temperate maritime plantation forests Forest Ecology and Management, 343, 144–156

J. A. Johnson, J.A., Aherne, J. and Cummins, T. 2013. Contrasting responses of two Sitka spruce forest plots in Ireland to reductions in sulphur emissions: results of 20 years of monitoring. Biogeochemistry, 116, 15-37.

Lal, R. 2007. Soil science and the carbon civilization. Soil Science Society of America Journal, 71 (5), 1425–1437.

May, L., Place, C., O'Hea, B., Lee, M., Dillane, M., McGinnity, P. 2005. Modelling soil erosion and transport in the Burrishoole Catchment, Newport, Co. Mayo, Ireland. Freshwater Forum, 23, 139–154.

Minkkinen, K., Byrne, K.A. and Trettin, C.C. 2008 Climate impacts of peatland forestry. In Peatlands and Climate Change. M. Strack (ed.), International Peat Society and Saarijärven Offset Oy, Saarijärvi, Finland, pp. 98–122.

Montgomery, D.R. 2007. Dirt: The Erosion of Civilizations. University of California Press.

Ni Dhubháin, A. 1998. The influence of wind on forestry in Ireland. Irish Forestry, 55:105–103.

Nugent, C., Kanali, C., Owende, P.M.O., Nieuwenhuis, M. and Ward, S. 2003 Characteristic site disturbance due to harvesting and extraction machinery traffic on sensitive forest sites with peat soils. Forest Ecology and Management, 180, 85–98.

O'Driscoll, C., O'Connor, M., Asam, Z.-u.-Z., Eyto, E.d., Poole, R., Rodgers, M., Zhan, X., Nieminen, M., Xiao, L. 2014 Whole-tree harvesting and grass seeding as potential mitigation methods for phosphorus export in peatland catchments. Forest Ecology and Management, 319 (0), 176–185.

Redmond, J., Gallagher, G., Černý, M. and Russ, R. 2007 Ireland's nation forest inventory - results. In National Forest Inventory Republic of Ireland Proceedings of NFI conference M. Nieuwenhuis, J. Redmond and C. O'Donovan (eds.), Forest Service, Johnstown Castel Estate, Co. Wexford, Ireland.

Reidy, B. and Bolger, T. 2013. Soil carbon stocks in a Sitka spruce chronosequence following afforestation. Irish Forestry, 70 (1–2),

Renou, F. and Farrell, E.P. 2005. Reclaiming peatlands for forestry: the Irish experience. In: Stanturf, J.A. and Madsen, P.A. (Eds), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, Florida, USA. pp. 541–557.

Renou-Wilson, F., Bolger, T., Bullock, C., Convery F., Curry, J.P., Ward, S., Wilson, D., Müller, C. 2011. BOGLAND - Sustainable Management of Peatlands in Ireland. STRIVE Report No 75. Environmental Protection Agency, Johnstown Castle, Co. Wexford, p. 157

Rodgers, M., O'Connor, M., Healy, M.G., O'Driscoll, C., Asam, Z.-u.-Z., Nieminen, M., Poole, R.,Müller, M., Xiao, L. 2010. Phosphorus release from forest harvesting on an upland blanket peat catchment. Forest Ecology and Management, 260 (12), 2241–2248.

Rodgers, M., O'Connor, M., Robinson, M.Muller, M., Poole, R., Xiao, L. 2011. Suspended solid yield from forest harvesting on upland blanket peat. Hydrological Processes, 25, 207–216.

Tiernan, D. 2007. Environmental and social enhancement of forest plantations on western peatlands - a case study. Irish Forestry, 64, 5–16.

Tiernan, D. 2008. Redesigning afforested western peatlands in Ireland. In: Farrell, C.A., Feehan, J. (Eds.), After Wise Use - The Future of Peatlands. 13th International Peat Congress. The International Peat Society, Finland, Tullamore, Co. Offaly, Ireland, pp. 520–523.

United Nations. 2004 World Population to 2300. Department of Economic and Social Affairs/Population Division 1.

Walsh, S. 2010. A summary of climate averages for Ireland 1981-2010. Climatological Note No. 14. Met Eireann, Dublin.

Wellock, M.L., LaPerle, C.M. and Kiely, G. 2011. What is the impact of afforestation on the carbon stocks of Irish mineral soils? Forest Ecology and Management, 262, 1589–1596.

Protection of British forest soils in a changing management and policy challenges

Elena Vanguelova

Forestry in Great Britain

Current British forest resources on averaged representative for the 3 countries (Scotland, Wales and England) has a forest cover of 3.1 Mha representing 13% of the land cover in Britain. Of this lower proportion of 0.8 Mha is public forest directly managed by the Forestry Commission and the rest is private. Conifers are little prevailing but overall half of the woodland is broadleaved and half is conifer of which most is productive conifers (Forestry Statistics, 2014). The forests and woodlands provide important ecosystem services. Forests overall protect soils and water and it is of vital importance for biodiversity, cultural and recreational use and benefits (Quine *et al.,* 2011). In addition, British forests produce timber of which 8.4 Mt softwood and 0.4 Mt hardwood per year, which links to the highly managed productive conifers compared to more native low managed broadleaves woodlands (NFI report, 2014). Inevitably, forests represent large carbon stock and potential for carbon sequestration (Morison *et al.,* 2010, 2012, Vanguelova *et al.,* 2013, NFI report, 2014). Existing UK forests, including soils, are a large store of carbon, with UK total carbon stocks aboveground and belowground of nearly 1000 Mt C. In most woodlands 74% of carbon is stored in the soil than in trees (Figure 1). Carbon density is twice as high in organic soils, compared to mineral soils and C in peat soils reaches 11% of the total carbon stocks in British forestry (Figure 2). Litter layer in forestry should not be ignored as it could be disturbed through management but together with deadwood makes 4 % of total forest carbon balance. Thus forestry could make a significant contribution to meeting the UK's challenging Green House Gases (GHG) emissions reductions targets and woodland creation was recognised as highly cost-effective and achievable abatement (Read *et al.,* 2009).

This lead to the UK ambitions, initiatives, and targets for woodland creation with latest governmental commitments to increase woodland cover with 2% in England, 8% in Scotland and 3.5% in Wales (DEFRA, 2013; FC Scotland, 2009). The current productive forestry as planted through the last century is mainly on poor and highly organic upland soils and the native and broadleaves woodland is distributed more in the lowlands and more marginal and nutrient richer soils.

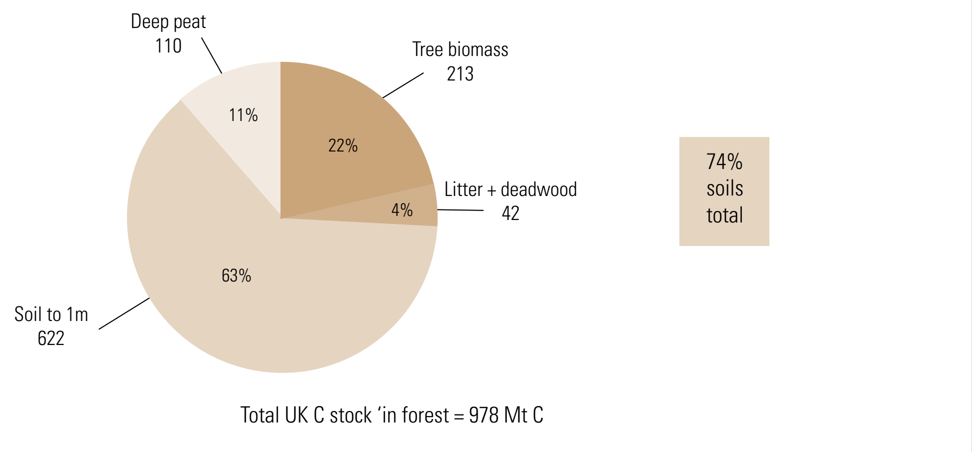

Figure 1. UK total carbon stocks in tree biomass, litter, deadwood and soils (Morison *et al.,* 2012, Vanguelova *et al.,* 2013, NFI report, 2014)

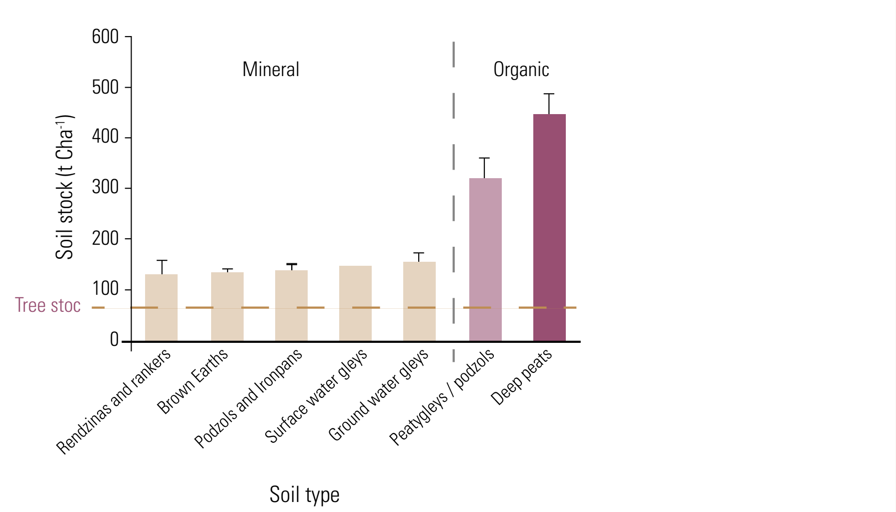

Figure 2. Averaged soil carbon stocks for each main forest soil type (Vanguelova *et al.,* 2013). Vertical line separates mineral with organic soil types and horizontal green line represents the averaged tree carbon density (NFI report, 2014).

Pressures and Risks to forest soils

Forest management pressures

The soil is an irreplaceable dynamic living resource that underpins the whole forest ecosystem. The soil has many vital functions such as providing tree anchorage, water, oxygen and nutrients for plant growth. It also stores carbon, acts as a filter for pollutants, protects archaeological remains and provides a habitat for soil organisms. These soil functions are supported by soil chemical, physical and biological processes, most of which are strongly regulated by biotic and abiotic factors.

Forests and woodland succession influence soil development differently compared to highly managed soils such as agriculture. Forest soils have well developed organic layers, more coherent soils structure and different biotic and carbon balances, so overall is less disturbed than agricultural soils. Managed forest makes a larger proportion of British woodland (NFI report, 2014), so forest management is one of the biggest pressures on forest soils. The new concept of Duncker *et al.,* (2012) of a framework for classifying different Forest Management Alternatives (FMA) along a gradient of intensity of intervention with the natural processes in a forest distinguished five FMA. They have different objectives, from maximizing biomass production and revenue from timber to multibenefits and preserving natural processes without human intervention (Figure 3).

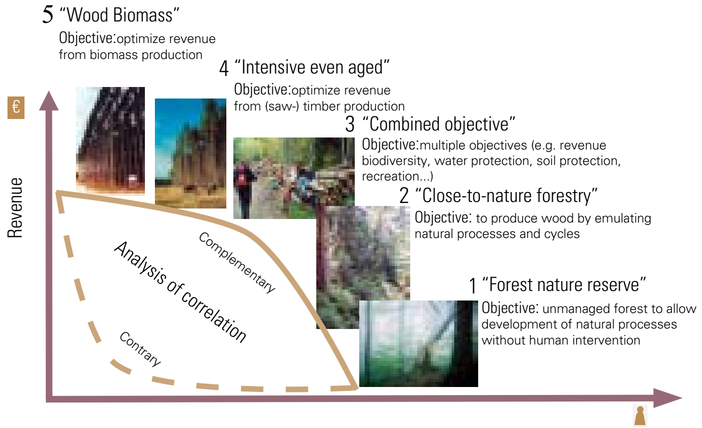

Figure 3. Forest Management Alternatives Concept as proposed by Duncker *et al.* (2012).

The current UK distribution of the five forest management alternatives shows the largest proportion to intensively managed even aged forestry (Mason and Perks, 2011; Figure 4a). This relates to the release of GHG under machine operations across the five management alternatives and the different operations, associated with these management alternatives such as transport, cultivation, thinning and harvesting, showing the largest GHG release during harvesting operations and overall increase with increase of the intensity of management (Mason and Perks, 2011; Figure 4b). This is also linked with the highest potential for carbon sequestration by the most intensively managed alternatives (Mason and Perks, 2011; Figure 4c).

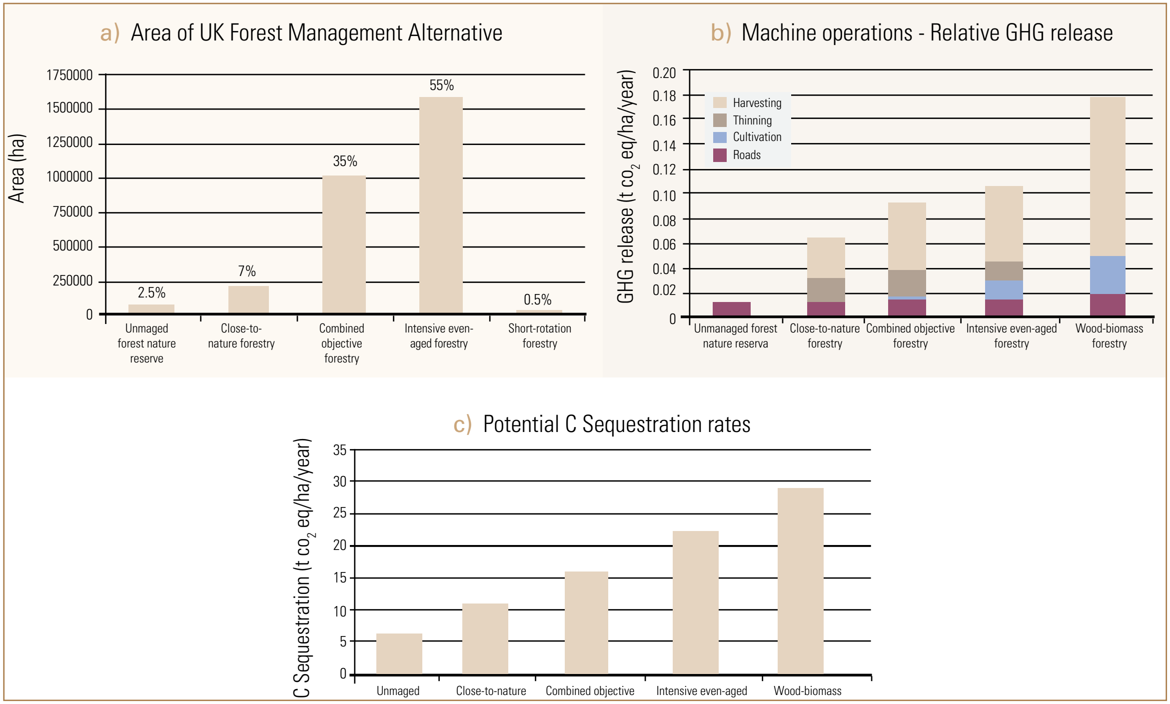

Figure 4. Area of UK forests in each of the forest management alternatives (FMA) (a), the Green House Balance associated with machine operation during different operations across the different FMA (b) and the potential carbon sequestration rates (Mason and Perks, 2011).

Helping to tackle green house emissions for climate change mitigation, carbon sequestration potential and multibenefits provided by forests have been priorities for the woodland creation but also reforestation (FC

Scotland, 2009; DEFRA, 2013). Trees can help to mitigate climate change by sequestering carbon (Read *et al.,* 2009; Morison *et al.,* 2012). However, in some circumstances forestry operations on deep peats may result in an overall release of carbon due to changes in the soil (Morison *et al.,* 2010).

Therefore, on deep peats, (<50 cm deep), forest managers should consider the carbon impact of management options alongside other priorities such as timber production, biodiversity and wider landscape values. Conventional management, include potential risks to soil disturbance through the ground preparation, thinning process and harvesting. Some long term observations suggest that with the increase in the intensity of ground preparation, there is an increase of the soil disturbance. From 2% of the soil disturbed by only hand planting to almost 75% disturbance when you applied the most intensive techniques such as trench mounding, draining and destumping (Bill Rayner, FR, personal communication). If only change practices from historically deep ploughing to shallow ploughing in current days the soil disturbance could be reduced from 35-50% down to 18-28% and down to 4-12% when even no ploughing is practiced. Such soil disturbance was quantify in terms of soil carbon stocks in a chronosequence study by Zerva *et al.,* 2005 from Kielder forest where soil C stocks in peaty gley soils decreased by 25-30% after first rotation forestry compared to the unplanted grassland. This impact may be minimal in different soil types, which are less sensitive to C loss.

Through the forest rotation, the next impacts on the soils could be from regular thinning operations, wood extractions and final clearfelling. Soil physical damage due to wood extraction in surface water gley soils when done during the winter and without brash mats, was demonstrated with double increase of the depth of the ruts with number of machines passes (Moffat *et al.,* 2010; Figure 5.). Soil C loss of about 15-20% was observed due to clearfell of Sitka spruce on peaty gley soils (Zerva et al., 2005).

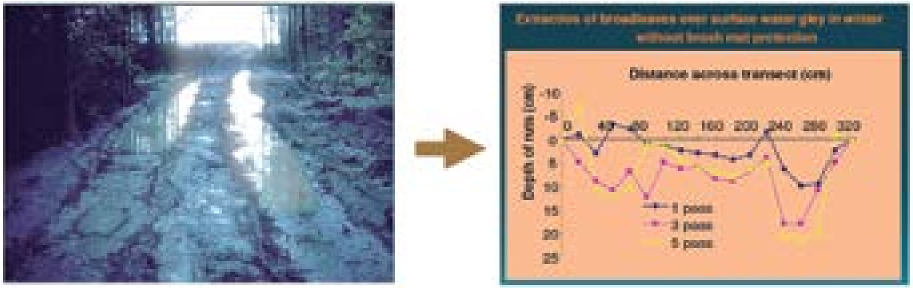

Figure 5. Extraction of broadleaves over surface water gley soils in winter without brash mat protection (left) and the depth of soil ruts after number of machine passes (right) (Moffat *et al.,* 2010).

UK and EU energy policies are driving the development of renewable energy sources as a way of cutting greenhouse gas emissions. Woody biomass is one of the more reliable renewable fuels and has the potential to make a significant contribution to meeting renewable energy targets (Forestry Commission, 2007). There are a number of different sources of woody biomass, including existing woodland, woodland creation, arboricultural arisings, sawmill co-products and recovered wood. Two sources that have been attracting increasing attention in recent years are the harvesting of woody residues, in the form of branches, tree tops and stumps, from existing conifer plantations and the creation of Short Rotation Coppice (SRC) and Short Rotation Forests (SRF) dedicated to growing biomass. The economic and carbon mitigation gains from exploiting these sources of woody biomass, however, could be offset by their impacts on soil. In particular, the removal of woody residues poses a number of hazards to the forest environment that could threaten sustainable forest management (LTS International, 2006). There are three principal threats:

1. Machine trafficking causing soil physical damage such as compaction, rutting and erosion, leading to increased turbidity and siltation of local watercourses.

2. Removal of essential nutrients (nitrogen, phosphorus and potassium) and carbon in residues, leading to lower soil fertility, potential loss of tree growth in subsequent rotations, and reduced soil carbon storage.

3. Removal of base cations (calcium, magnesium, sodium and potassium) reducing soil buffering capacity and leading to increased soil and stream water acidification.

SRC and SRF are thought to pose less of a threat to soil, especially in relation to the previous land use (Vanguelova and Pitman, 2011a). Impacts are limited by the better conditions that characterise planting sites, such as gentler slopes and higher quality soils. The main risks are considered to be:

1. Machine trafficking causing soil physical damage such as compaction and rutting.

2. Removal of essential nutrients in biomass, leading to lower soil fertility and potential loss of tree growth in later rotations.

3. Increased crop water use resulting in reduced groundwater recharge and ecological flows.

Environmental pressures

The climate of the UK has changed as a result of global emissions of greenhouse gases and an increase in mean annual temperature is particularly evident (approximately 1°C since the 1970s). Current climate projections (UKCP09; www.ukcip.org.uk) indicate that the climate will continue to warm throughout this century and there will be changes in rainfall and its seasonal distribution. These changes will vary regionally (for example, more drying is likely in the south east of the UK than elsewhere), but there is inevitably uncertainty in the magnitude and timing of such projections. An understanding of how climate change will affect the ecological suitability of individual tree species and their growth is essential for forest management. However, these both depend on how the soil conditions change in response to climate change. Key soil properties and processes that will be affected by climate change include soil organic matter content, soil water and nutrient balance and soil erodibility. Changes in the main soil functions occur within days (e.g. in soil moisture and temperature), months (e.g. soil nutrient status), years (e.g. organic matter content) and tens and thousands of years (e.g. soil mineral weathering). However, the speed of all these processes could be affected by changes in climate (Bradley *et al.,* 2005; Vanguelova et al., 2011).

In addition to forest management other pressures and potential risks to forest soils include natural phenomenon such as windrows which can have a substantial impact in some sloppy forests in the uplands, but also fires and pests and diseases both likely to increase with climate change. In relation to those, it is of great importance to plant the right tree or forest type on the right place in order to minimise these potential impacts and maximise the long term forest productivity by matching the tree demand for water and nutrients with their supplies (FC Scotland, 2010). Taking into account the atmospheric pollution, the pressure from sulphur deposition has declined significantly and soil recovery from acidification in some very historically polluted areas have been observed, but forests in pristine areas could become S deficient (Vanguelova et al., 2010). However, the deposition of nitrogen is still on the rise (RoTAP, 2012) and will continue to present pressure for forest soils in view of forest and soils euthrophication especially in England where there is intensive agriculture and farming (Vanguelova and Pitman, 2009, 2011c).

Soil protection

The United Kingdom Forestry Standard (UKFS) is the reference standard for sustainable forest management in the UK. The UKFS, supported by its series of Guidelines, including the forest and soils, outlines the context for forestry in the UK, sets out the approach of the UK governments to sustainable forest management, defines standards and requirements, and provides a basis for regulation and monitoring – including national and international reporting (UKFC, FC Forest and Guidelines, 2011). Sustainable forest management involves ensuring that the production of all forest and woodland benefits is maintained over the long term. This is achieved when the environmental, economic and social functions of forests and woodlands are interacting and in support of each other. The precise point of balance between environmental, economic and social functions will vary in individual forests and woodlands in response to management objectives and local circumstances. The concept of balanced objectives is central to the approach of the UK Forestry Standard.

A range of guidance has been developed by the Forestry Commission and others to help address the threats posed to soil and water by the harvesting of woody residues or planting of SRC. The likelihood and magnitude for damage depends on site sensitivity and on many sites can be effectively controlled by good forest planning and management. On some sites and locations the risks are considered to be too high to support such practices and it is recommended that these be avoided. Recent guidance published by Forest Research adopts a risk-based approach to identifying suitable sites for brash removal and stump harvesting (Forest Research, 2009 (a) and (b)). There is past and current guidance on advice to minimise impacts and protect peatlands resources and their wider multi-benefits (Patterson and Anderson, 2000; Cariss, 2014, FC Scotland). This guidance is based on and is continuously improved by underpinning ongoing research, strategic spatial assessments, and field assessments toolkit and guidance (Morison *et al.,* 2010; Vanguelova *et al.,* 2011, FC Wales, 2012). For example, in the past it was allowed to plant forestry on peat as deep as 1 m (Patterson and Anderson, 2000), now revised guidance allows planting on peats only as deep as 50 cm.

In addition to the UKFS and the FC and FR guidelines and guidance developed, there are a few initiatives through which soil is expected to be better protected. The recently developed and launched Woodland Carbon Code (http://www.forestry.gov.uk/carboncode) by the Forestry Commission is voluntary standard for woodland creation projects in the UK which will make claims about carbon they sequester and encourage private owners to engaged in woodland creation, all done following the best practices guidelines available. Additionally, the current forest management practices are moving towards less intensive management such as Continuous Cover Forestry is an approach to forest management that seeks to create more diverse forests, both structurally and in terms of species composition, by avoiding clearfelling (Stoke and Kerr, 2009). The development of more diverse forests is a sensible way to reduce the risks posed by future changes in the climate and biotic threats and could be beneficial to soil protection in terms of nutrient capacity, carbon and biodiversity.

Ongoing research

The available guidance is largely based on expert judgement of the scientific issues informed by practical experience of managing forest soils. Uncertainties remain about the long-term sustainability of energy forestry on certain soil types and locations, especially in terms of carbon loss, but also for soil fertility, acidification and water use. There is a particular need for data on soil carbon to support full life-cycle analyses and to compare energy forestry with other bioenergy systems. Work is required to quantify impacts and clarify the susceptibility of different soils, as well as to evaluate opportunities for using energy forestry in a more targeted way to benefit soils, diffuse pollution and flood management. Research is needed to quantify the carbon changes in peat and peaty soils under forestry to fully underpin the guidance and policy for peatland preservation and restoration.

Various studies are planned or underway to address these issues, especially in relation to the harvesting of woody residues, the establishment of SRF systems and the impacts of forestry on peat soils. Information needs on most of the impacts of SRF are met by a series of earlier reviews and reports (LTS, 2006: Vanguelova and Pitman, 2011). Environmental impacts of stump harvesting have been reviewed by Pitman, 2008 and Walmsley and Godbold, 2009. Studies on the impact of harvesting brash are ongoing at Kielder in North England (Vanguelova *et al.,* 2010), and Beddgelert in North Wales (Walmsley *et al.,* 2009), while one on evaluating the environmental impacts of stump harvesting is in place in mid Wales. Work on SRF involves baseline soil assessments at five recently acquired farms distributed across Scotland and six in England that are being planted with a range of potential tree species. Two of the sites in Scotland and one in England will be the subject of studies to assess the impact of SRF on water quality and/or quantity and on all sites soil baselines has been established. Research is ongoing on quantifying the carbon stocks and changes in peat and peaty soils under forestry by carrying out chronosequence experiments and long term monitoring. The results from these studies will be fundamental to soil protection by testing and further development of existing guidance, improving carbon accounting models and in demonstrating whether the guidance is fit for purpose.

References

Bradley, I., A.J.Moffat, E. Vanguelova, P. Falloon & J. Harris. 2005. Impacts of climate change on soil functions. DEFRA project, report SP0538, London.

Cariss, H. 2014. Forestry and Deep peat. Guidance on Peat Soils. Forestry Commission, Wales. http://www.forestry.gov.uk/pdf/GuidanceonpeatHCv7.pdf/$FILE/GuidanceonpeatHCv7.pdf.

DEFRA, 2013. Government Forestry and Woodlands Policy Statement Incorporating the Government's Responseto the Independent Panel onForestry's Final Report. http://www.defra.gov.uk/rural/forestry/panel-response/.

Duncker, P. S., S. M. Barreiro, G. M. Hengeveld, T. Lind, W. L. Mason, S. Ambrozy, and H. Spiecker. 2012. Classification of forest management approaches: a new conceptual framework and its applicability to European forestry. Ecology and Society 17(4): 51. http://dx.doi.org/10.5751/ES-05262-170451.

Forestry Commission. 2007. A woodfuel strategy for England. Forestry Commission England, Bristol.

Forestry Commission Scotland. 2009. Strategy The Scottish Government's rationale for woodland expansion, 2009 Forestry Commission Scotland.

Forestry Commission, Scotland. 2010. The right tree in the right place, 2010 – Advice. Forestry Commission Scotland - May 2010, ISBN - 978 0 85538 805 8.

Forest Research. 2009a. Guidance on site selection for brash removal. Forest Research, Farnham, UK. http://www.forestresearch.gov.uk/pdf/Brash_residue_protocol.pdf/$FILE/Brash_residue_protocol.pdf.

Forest Research. 2009b. Stump harvesting: Interim guidance on site selection and good practice. Forest Research, Farnham, UK. http://www.forestresearch.gov.uk/pdf/FC_stump_harvesting_guidance_April09.pdf.

Forestry Statistics. 2014. http://www.forestry.gov.uk/website/forstats2014.nsf/LUContentsTop?openview&RestrictToCategory=1.

LTS International. 2006. A Review of the potential impacts of Short Rotation Forestry, LTS International Ltd, Edinburgh.

Mason, Bill and M. P. Perks, 'Sitka spruce *(Picea sitchensis)* forests in Atlantic Europe: Changes in forest management and possible consequences for carbon sequestration', Scandinavian Journal of Forest Research, iFirst article, 1-10.

Moffat, A.J., I. Murgatroyd, T. R. Hutchings and F. M. Kennedy. 2010. Hardwood timber extraction over sensitive soils – a terramechanical study in southern England. Quarterly Journal of Forestry 104, 181-189.

Morison, J., E. Vanguelova, S. Broadmeadow, M. Perks, S. Yamulki and T. Randle. 2010. Understanding the GHG implications of forestry on peat soils in Scotland. Forest Research report for FC Scotland, May, 2010, 43pp.

Morison, J., R. Matthews, G. Miller, M. Perks, T. Randle, E. Vanguelova, M. White and S. Yamulki. 2012. Understanding the carbon and greenhouse gas balance of forests in Britain. Forestry Commission Research Report, Forestry Commission, Edinburgh, 149pp.

National Forest Inventory Report. 2014. Carbon in live trees in Britain. National Forest Inventory Report, Forestry Commission ISBN: 978-0-85538-907-9. http://www.forestry.gov.uk/pdf/FCNFI113.pdf/$FILE/FCNFI113.pdf.

Read, D.J., P. H. Freer-Smith, J. I. L. Morison, N. Hanley, C. C. West and P. Snowdon (eds). 2009. Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The synthesis report. The Stationery Office, Edinburgh.

RoTAP. 2012. Review of Transboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. Summary for Policy Makers. Contract Report to the Department for Environment, Food and Rural Affairs. Centre for Ecology & Hydrology.

Quine, C. P., C. Cahalan, A. Hester, J. Humphrey, K. Kirby, A. Moffat and G. Valatin. 2011. Ch 8 Woodlands.in R.Watson and S.Albon, editors. UK National Ecosystem Assessment. UNEP & Defra.

Patterson, G.S. and A.R. Anderson. 2000. Forests and peatland habitats. Guideline Note No.1. Forestry Commission, Edinburgh.

Pitman, J. I. 2008. A review of the environmental impacts of tree stump harvesting on UK coniferous forests. Forest Research Report, Forest Research Contract CR2007/08/164, May, 2008.

Stokes, V and G. Kerr. 2009. The evidence supporting the use of CCF in adapting Scotland's forests to the risks of climate change. Report to the Forestry Commission Scotland by Forest Research. Alice Holt Lodge, Farnham, Surrey, England.http://www.forestry.gov.uk/pdf/CCF_and_Climate_Change_Report.pdf/$FILE/CCF_and_Climate_Change_Report.pdf.

Vanguelova, E.I., R. Pitman, J. Luiro and H-S. Helmisaari. 2010. Long term effects of whole tree harvesting on soil nutrient sustainability in the UK. Submitted to Biogeochemistry.

Vanguelova, E.I., S. Benham, R. Pitman, A. Moffat, M. Broadmeadow, T. Nisbet, D. Durrant, N. Barsoum, M. Wilkinson, F. Bochereau, S. Broadmeadow, T. Hutchings, P. Crow, T. Durrant-Huston and P. Taylor. 2010. Chemical fluxes in time through forest ecosystems in the UK – soil response to pollution recovery. Environmental Pollution 158 (5): 1857-1869.

Vanguelova E. and R. Pitman. 2011a. Impacts of Short Rotation Forestry on Soil Sustainability. In McKay, H. (ed.) Short Rotation Forestry: review of growth and environmental impacts. Forest Research Monograph, 2, Forest Research, Surrey, 212pp. ISBN 978-0-85538-827-0.

Vanguelova, E., A. Moffat, J. Morison and S. Martin. 2011. Can we manage the impacts of changing climate on our forest soils? Forestry & Timber News, June, p. 11-12.

Vanguelova, E. and R. Pitman. 2011b. Impacts of N inputs on forests and forest soil biogeochemistry in Great Britain. Paper in proceedings of "Nitrogen & Global Change – Key findings – future challenges", April 11-15, 2011, Edinburgh, UK.

Vanguelova, E.I., T. R. Nisbet, A. J. Moffat, S. Broadmeadow, T. G. M. Sanders and J. I. L. Morison. 2013. A new evaluation of carbon stocks in British forest soils. Soil Use and Management, 29, 2, 169-181.

Walmsley, J.D. and D. L. Godbold. 2009. Stump Harvesting for Bioenergy –A Review of the Environmental Impacts. Forestry 83, 17-38.

Walmsley, J.D., D. L. Jones, B. Reynolds, M. H. Price and J. R. Healey. 2009. Whole tree harvesting can reduce second rotation forest productivity. Forest Ecology and Management. 257, 1104-1111.

Zerva, A. and M. Mencuccini. 2005. Carbon stock changes in a peaty gley soil profile after afforestation with Sitka spruce *(Picea sitchensis).* Annals of Forest Science, 62, 873–880.

Land degradation risks to forests in Aquitaine: emphasis on *Pinus pinaster* plantations

Mark R. Bakker and Laurent Augusto

Introduction

Astérix and Obélix were probably right when they defended their territory in Gallia against the Romans: large scale land degradation – i.e. strong deforestation around the Mediterranean basin – occurred during the Roman era and was related to increases in population, agricultural expansion and strong economic growth (Mather *et al.* 1999, Williams 2002, Pongratz *et al.* 2008). The Germans cite statements made by von Carlowitz in 1713 on 'sustained yield' (no more harvest than what the forest produces), describing this author as a pioneer in the intellectual framework leading to 'sustainable production'. The French might rightfully claim that their heroes raised awareness about the concept of sustainable production much earlier, although it could be argued that their motivation - to acquire wild boar meat from nearby forests after beating up yet another squadron of Roman soldiers - only loosely matches this general concept. Throughout history, episodes of deforestation and agricultural expansion have been followed by agricultural abandonment and natural – or since the mid-19th century – artificial reforestation (Buijs 1985, Watkins 1993, Mather *et al.* 1999, Wilson 2004). There is a long tradition in Europe of legislation on forest use aimed at continued use of forest products by at least some of the users (e.g. game for noblemen) (Buijs 1985, Wilson 2004), but which has been unsuccessful in preventing deforestation in the longer run. The lowest rates of forest cover in Europe generally occurred between 1700 and 1900 in most European countries (Kaplan *et al.* 2009, FAO 2012), and by the end of the twentieth century forest areas in all of Europe were stable or increasing (FAO 2012) as a result of political incentives, private investment and to some extent market demands (Sargos 1997).

Over the last few decades, in view of the expanding population, the inherent needs for resources and also the increasing pollution levels worldwide, efforts made by the international community have led to many meetings, reports, processes, intergovernmental bodies and protocols (such as the Montreal process, the Kyoto protocol, IPCC reporting, and Millennium Ecosystem Assessment). Regarding forests, the focus over the last few decades has been to promote the use of social, economic and environmental criteria for ecologically sustainable forest management (Raison *et al.* 1997). More recently, the Millenium Ecosystem Assessment (2005) has conceptualized the links between human needs and ecosystem services that can be provided by forests. In the absence of sustainable management of forests, degradation of forest land and/or deterioration of the associated services may occur. Land degradation has been defined as "the reduction in the capacity of the land to provide ecosystem goods and services, over a period of time, for its beneficiaries" (FAO 2013, LADA project). Degradation of forest land may affect the provision of both ecosystem goods and services, although perhaps to a lesser extent in Europe than in other more vulnerable regions of the world (see e.g. FAO 2013, the LADA project). "Ecosystem goods", which are defined here as products of land that have an economic and/or social value, include land availability, animal and plant production, soil health and water quantity and quality (FAO 2013, LADA project). "Ecosystem services" include biodiversity and the maintenance of hydrological, nutrient and carbon cycles (FAO 2013, LADA project). Land degradation is not necessarily confined to biophysical effects, nor is it limited to human-induced phenomena, and it also includes natural impacts and effects (FAO 2013, LADA project). We categorized the main services that may suffer as a result of land degradation in forests from the following points of view: i) biomass, ii) soil quality, iii) water resources, iv) biodiversity, v) economic productivity and vi) social and cultural services. In the following we will describe the main known and expected threats to ecosystem services in relation to degradation of the forests in Aquitaine. Our contribution is restricted to forest plantations of *Pinus pinaster* in this area and considers expert judgement in combination with information reported in the literature.

Description of the forest range

Aquitaine is an administrative area ('region') in the southwest of France (Figure 1a) and is currently composed of five smaller administrative entities ('departments'). Larger forest areas are found in the Dordogne (north east), the Pyrenees (south to southeast) and the Landes forest range (Figure 1b). The description of the forest range – and potential threats leading to land degradation – will be restricted to the Landes forest range (based on Trichet *et al.* 2009; Augusto *et al.* 2010 and references therein). The total surface area of the Landes de Gascogne area is around 1.3 million ha, of which around 0.9 million ha is covered by forest mainly comprising *Pinus pinaster* (more than 85% of the surface area). Around 90 % of the forest is privately owned. Most forests were established in the mid-19th century on former inland moorland varying in water table characteristics (dry, mesic and humic moorlands) and in the 18th century on coastal dunes. In some locations, pine forests were already present before large-scale plantations were installed. Most of the stands are intensively managed as monospecific, even-aged stands, generally with rotation lengths of between 35 and 65 years. Harvesting is typically carried out by clearcutting. Soils in the moorland sites have developed from a coarse sandy Aeolian parent material deposited in the Pleistocene, and they are characterized by low fertility, a low organic matter content and high acidity. They can be classified as Orsteinic to Albic Podzols (WRB classification: FAO/IUSS, 2006). Lenses of cemented spodic horizons can occur irregularly between depths of 40 and 100 cm in the soil. In the coastal dunes (comprising a succession of a few lines of dunes more or less parallel to the coast), the parent material of the soils originated from Aeolian deposits during the Holocene period, and the soils are classified as Arenosols. With the exception of the dunes, the topography in the Landes forest range is flat and the drainage system comprises only a few streams (Figure 1c).

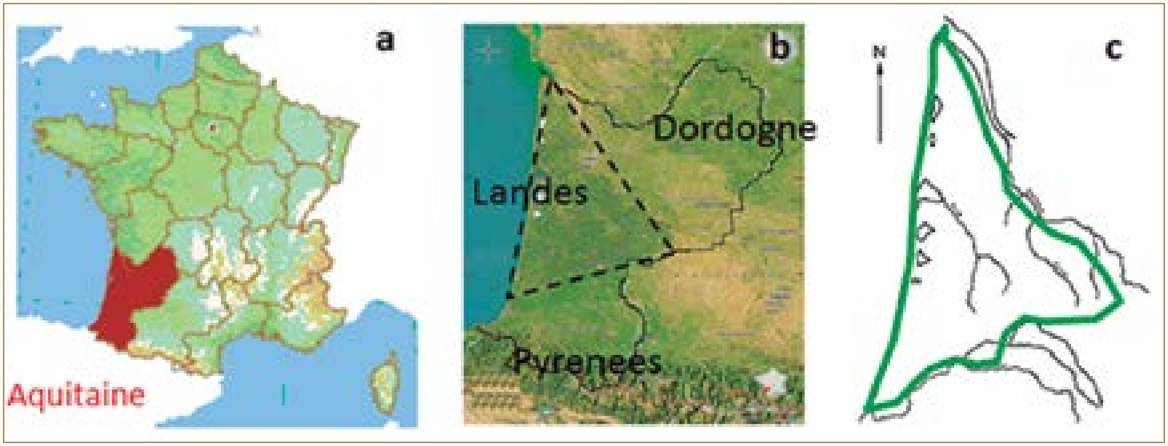

Figure 1. Location of (a) Aquitaine in France, and (b) the major forest ranges in Aquitaine; (c) the drainage system within the 'Landes triangle', indicated in green, includes very few streams.

The Landes forest area is mostly a man-made planted forest, originating from a political desire (Napoleon III, law of 1857) to plant trees in the 'rough and unused moorlands'. In fact, moorlands were useful for agro-pastoral purposes (Sargos 1997; Webb 1998), but were economically less profitable than pines - given the high resin prices at that time. Forest cover was therefore quite substantial a few decades later, around 1900 (Figure 2a). As a result of low resin prices and improved forestry management practices (genetic selection, line cropping, P fertilizer applications, see Trichet *et al.* 2009), resin production gradually ceased and monoculture plantations destined for wood and paper industry became dominant after the Second World War. Major events in relation to the *Pinus pinaster* production system include large forest fires in the 1940s (see Figures 2a and 2b, which show much lower forest cover in 1947), transformation of a non-negligible area of forest into agricultural land (maize cropping, see Figure 2c) and two major storms, in 1999 and 2009, which jeopardized supply to the wood industry and devastated the moral of forest owners. Most forest entities (publicly owned or managed, privately owned and covering more than 25 ha) are operated under simplified management schemes (PSG in French, *"plan simple de gestion"*) and most of the surface area is subject to the PEFC-Aquitaine certification system. The forestry sector in the Landes forest range is very important economically within the Aquitaine region; representatives from public organizations and the wood industry sector have made considerable efforts since the storms of 1999 and 2009 to develop prospective schemes for the future of this forest area (see GIP Ecofor 2010, Mora *et al.*2012).

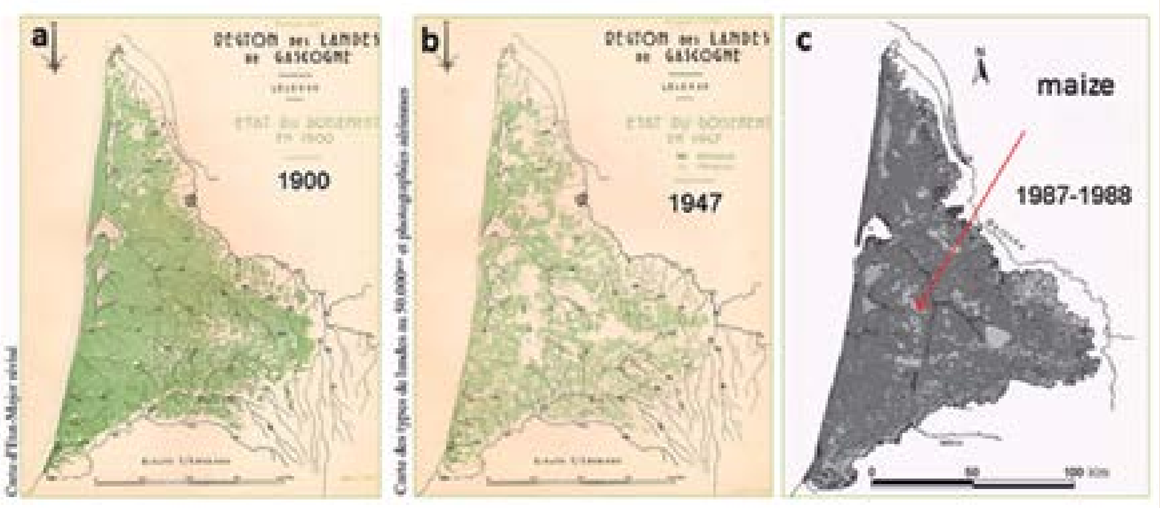

Figure 2. Land under forest cover in the Landes triangle (a) in 1900, (b) in 1947, after several severe forest fires, and (c) in 1987-1988, showing some areas that are being transformed into agricultural land (mainly for maize growing). Images from Jolivet *et al.* 2007.

Threats of Land Degradation for the main types of ecosystem service

Biomass and land cover

The classical management system (resin production, timber harvesting, rotation length 80–90 yrs) persisted until around 1940. As resin prices decreased, this was gradually replaced by more intensive plantation forestry (40–60 yr rotation length, genetic selection, soil preparation, P fertilization), which gradually led to increased annual productivity. However, although the forest range was almost fully stocked with *Pinus pinaster* trees around 1900 (Figure 2a), several factors led to loss of forest cover over time (including forest fires, storms, severe winters and transformation to alternative land uses).

Forest fires, particularly in pine plantations, are a continuous threat to the forests in the Landes de Gascogne region. The largest forest fires occurred in the 1940s. As a result, forest cover was lower in the 1940s (see Figure 2b) than before (Figure 2a). Forest fires destroyed over 150 000 ha of land in 1949 alone. At present, due to understory control (less fuel available for fires in the forest), reinforced protection (dense networks of water reservoirs and of roads for rapid access) and surveillance (DFCI, Défense des Forêts Contre l'Incendie), outbreaks cause much less damage to the forest. In practice, the density of wildfires in SW France is comparable to that in many other Mediterranean regions, although each fire event is generally restricted to a small area due to rapid detection and effective interventions (e.g. by the use of aircrafts). However, forest fires may increase under the predicted climate change scenarios (lower precipitation, longer periods of summer drought). Storms have also caused large-scale damage to the forest. Heavy storms were reported in 1883, 1915, 1976, 1999 and 2009 (Pottier 2013). The latter two storms were described as 'storms of the century'. The 1999 storm damaged 238 000 ha of forest, and the 2009 affected 600 000 ha of forest (of which 200 000 ha was severely affected, after Pottier 2013). Climate models predict a greater frequency of extreme events, such as storms, during the next century, and therefore so-called *storms of the century* may occur more often. Severe winters have also caused frost damage (leading to death of trees), in particular in 1956, 1963 and 1985, with 100 000 ha of forest affected in 1963 and 30 000 – 50 000 ha in 1985. Indeed, after the huge wildfires that occurred in the 1940s, there was a local scarcity of pine seeds, and seeds were imported from other countries, mainly Portugal. The planting stock of southern origin (Portuguese) did not appear to be resistant to the frost that occurred in these years. As a result, plants and seeds of this origin are not promoted in the area. Severe frosts may be less likely to occur than in the past as a result of climate change, even though extreme events are not well predicted by climate change models. Prolonged summer droughts, as in 2003 (Bréda *et al.* 2003), are expected to occur more frequently over time. In 2003, in the irrigation experiments carried out at Pierroton, a positive effect of irrigation on forest growth was observed for the first time (P Trichet, pers. comm.) on a rather humid site (*wet moorland* site class; see Jolivet *et al.* 2007 and Augusto *et al.* 2010). Differences in the growth of trees on dry moorland and wet moorland sites are already striking. Overall, with increasing droughts and lowered water table it might be expected that productivity will be more and more constrained by water availability. Water use for adjacent agriculture (drainage by deep ditches, irrigation from the water table) will acerbate this locally.

Drought may also weaken the resistance of trees to pests. Attacks by scolytid beetles increased considerably after the 2009 storm (decaying trees not yet harvested from all of the stands), and pine processionary moths have also caused severe damage in many years. The expected arrival of the pine nematode in these huge monospecific plantations will probably add another dimension to 'forest pests' (given the levels of damage in some areas of Portugal and Spain) in this forest range, which is still largely unaffected by major pests. Whether due to fires, storms or pests, major damage to the stands would affect the decision making process of the owners. Stands can be replanted – and this has been done in most cases – but stands can also be transformed for other types of land use, particularly when large areas are impacted by such events. In the 1960s to 1980s, part of the area was transformed into agriculture land, with more than 100 000 ha being used for maize cropping (see Figure 2c, from Jolivet *et al.* 2007, Pottier 2013). After the last storm of the century (2009), the prospective study by Mora *et al.* (2012) indicated that forest cover may decline as a result of urbanization, needs for infrastructure (railroads, motorways and others) or – in view of better potential return on investment – transformation of land for other types of use (e.g. agriculture, for solar energy farms). Forest biomass may therefore decline over time as a result of the combined effect of poor growth conditions (less water), greater frequency of devastating events (storms, droughts, perhaps fires, pine nematodes) and the more gradual process of transformation of forest land for alternative purposes.

Soil health

Soils in most stands are usually limited by P availability, i.e. in *wet moorlands* and mesophylous moorlands (Trichet *et al.* 2009). In the *dry moorlands* and *dunes,* N and locally K or Mg, will probably limit plant growth (Augusto *et al.* 2010). P fertilization has been used since the 1960s (Trichet *et al.* 2009). Fertilizer use might be pursued indefinitely (depending on the availability of mineral P sources), but can be costly and the tendency is to use less P fertilizers than prescribed in the 1960s-1980s (Trichet and Augusto unpublished results, based on a survey among forest practitioners). In recent years it has been suggested that harvesting could include tree parts other than the stems (i.e. branches with or without needles, stumps, coarse roots, and adhering fine roots close to the stumps) in order to optimize the harvesting efficiency and to make use of unconventional wood products in the heating / energy cycle of factories. This would yield wood ash, which could potentially be used as a multi-nutrient fertilizer (although lacking in N) in the forest (Augusto *et al.* 2008). However, although ash supplies valuable amounts of P and increases the pH of these acidic soils, it also concentrates trace metal elements, which are potentially a source of pollution in the forest (Augusto *et al.* 2008), depending on the doses used. At the same time, experiments have been carried out to evaluate the possible use of sewage sludge or urban waste water in the forest, which may be another source of pollution (Augusto and Trichet, unpublished results; ongoing experiments). The aforementioned increase in harvesting intensity has been evaluated (Augusto *et al.* 2015) in relation to harvesting of stem only, stem + branches, stem + branches + foliage and stem + coarse roots. This showed that biomass harvest increased by 15–18% in these three harvest scenarios relative to the stem only scenario, but nutrient exports increased by 30–57% (in particular for N and P). When root systems (stumps and a circle with diameter of 25, 50, 75 to 100 cm around the stump) were harvested, biomass harvest increased by 20–25 % between stump only and stump + roots within a radius of 100 cm, but nutrient exports of N increased by 45 %. In both cases, increasing harvesting intensity is clearly not sustainable in terms of soil fertility (Augusto *et al.* 2015).

Using experiments combining penetrometers and soil analysis to evaluate the effect of silvicultural management practices (clear cutting or thinning with machinery), Dousseron (2006) showed that this did not lead to considerable compaction of the very sandy soils. One of the more noteworthy observations was that the disturbance led to redistribution of organic matter at the surface (depletion in some parts of the surface, accumulation in other zones). However, tillage of the soil between planted tree rows, usually within a few years of plantation, resulted in irreversible damage to structural roots at the early stages, leading to lower resistance to wind throw in later years (F. Danjon, ongoing work). This should be taken into consideration by forest managers. The increased drought expected under current climate change scenarios may also be important; indeed, organic matter could degrade faster, possibly leading locally to denuded soils (potentially increasing the risk of surface run-off, although the topography is generally flat). The water holding capacity of the topsoil, due to its sandy texture, strongly depends on the organic matter content, and therefore increasing the rate of degradation of organic matter may subsequently affect the availability of water to plants and trees. Our understanding of this possible effect of climate change is, for the moment, insufficient. Erosion risks may occur directly at local scales, i.e. in case of coastal or continental dunes and along river valleys; however, management objectives (environmental values, tourism, defence of the coast line and so on) and forest management may differ here, thereby minimizing such risks. Contamination of soils is so far not a problem in the Landes forests. However, trace metal elements are concentrated in wood ash (Augusto *et al.* 2008) and if such products were applied at high doses (i.e. spread over smaller forest areas rather than over a larger surface area), metal contamination could occur. Authorisation of such practices, and also of the use of sewage sludge or waste waters (in an experimental phase), should be done according to precise guidelines for maximum doses per unit of surface area and time, to avoid critical loads of pollutants entering the forest soil. Other aspects of soil health such as landslides and salinization are not of issue in this forest area (although some salty water from the sea may affect hydrological cycles in areas close to the coast). Overall, concerning soil health, due to limited fertility, intensification of harvesting may lead to lower potential productivity. Trace metal pollution may occur and increased organic matter degradation may also affect soil fertility (nutrient and water availability). Given the power of the local wood industry sector, intensification of harvesting is likely to occur.

Water resources

It has been suggested that water availability (based on precipitation level, depth of water table) is already decreasing in Aquitaine. Models predict temperature increases and changes in precipitation patterns. At the same time, for a higher CO_2 level, higher temperature and longer growing season more water would be needed, unless water use efficiency could be adapted by selection of more suitable provenances. Agriculture (maize cropping, deep ditches) results in drainage and lowering of the water table (irrigation) and could lead to depletion of water supplies for the forest. The already lower growth observed in the driest sites in the area may become more commonplace. The water quality will be affected, and the composition and functioning of the riparian zone along the streams or coastal lakes are also likely to affect the biodiversity of these wetland zones. Overall, although model predictions inherently include some uncertainties, water supply appears to be a key factor for future production.

Biodiversity

The forest area includes four main types of vegetation (see site description), all of which include one to three dominant understory species and maritime pine as the monospecific plantation species. The forest is the result of plantations established around two centuries ago in sites characterized at that time as open moorland and dunes. Therefore, many plant and animal species have reached the area from existing forests or from scattered forested areas within the area, although some species are characteristic of open areas and/or grassy areas. These species could be maintained due to the open canopy of the maritime pine forests and the clear cutting system used in this plantation forest (see chapter 2 of Mora *et al.* 2012). The species biodiversity in the forest therefore also depends on the open habitats present in this area, the coastal dunes and also on the presence of riparian environments and lakes. The local presence of deciduous trees – some of which are very old – is another factor explaining high biodiversity at some points. Thus, despite an overall not very high biodiversity associated with pure pine forests, some species that are perhaps uncommon in many regions of France are well represented in this forest range. These include birds such as the Nightjar *(Caprimulgus europaeus)*, the Dartmoor Warbler *(Sylvia undata),* the Short-toed Eagle *(Circaetus gallicus)* and the Hoopoe *(Upupa epops).* The European mink *(Mustela lutreola)* also has one of its last strongholds in this area (associated with riparian environments). If the forest persists, the biodiversity should also persist. Replacement of *Pinus pinaster* by other species could create additional habitats (increased biodiversity), although species specific to this environment would perhaps suffer (possible loss of target species). Overall, at the moment, biodiversity loss does not appear to be a critical issue.

Economic productivity

As long as the forestry sector remains economically attractive, the forest will survive. However, timber industry interests (continuous need for supply) may conflict with the interests of landowners and managers (i.e. intensive harvesting and short rotation systems may suit the industry but not the owners because these systems are sustainable from the perspective of one but not the other). Extreme events (e.g. the storm of 2009) have shown the vulnerability of the sector (e.g. as regards employment and maintaining the wood sector). Basically, if the economics are weakened, then degradation may occur. Likewise, if degradation of other factors interferes with production, then the economic function will be weakened.

Social and cultural services

A number of people are employed in the timber sector, live in the area and are attached to the forest in their surroundings. People use the forest for leisure activities (e.g. collecting mushrooms). Some studies on human well-being have indicated the benefits of the presence of forests to the local population and to those who use it for leisure activities. There is some awareness that this region should promote its coastal area for tourism, as well as the quiet adjoining forest areas. The services appear proportional to the size of the forest: if the forest remains intact, social and cultural services that rely on the forest will presumably also remain intact.

Discussion and Conclusion

There are two sources of bias in this ‘expert’ approach: 1) stronger expertise in some fields (soil sciences, fertility, and tree production) than in others (social and cultural services) and 2) time constraints for the construction of this document, including the recovery of all potentially valid sources of information. In relation to bias 1, it was easier to deal with time constraints in the fields we know more about. Our critical view of land degradation in the Landes forests in the southwest of France is thus imperfect: it includes useful knowledge, but also knowledge gaps.

However, we feel that at present land degradation (i.e. threatening the *Pinus pinaster* production forests and all related assets) is not a critical issue in Aquitaine.

The main risks for the next decades include the following:

- Loss of biomass (land cover) due to transformation of forest for other land use purposes (frequent fires or storms would accelerate this; new pests such as nematodes could be disastrous).

- Decrease in the soil health function (at least at the nutrient level in the case of increased harvesting).

- Increased occurrence of water stress and/ or incidences of water limiting growth.

All of these factors may lead to decreased production (economic production function potentially under pressure) and contribute to a net flux of deforestation (transformation to other land uses if the economic return on investment is not sufficient). Erosion, pollution, soil compaction appear negligible. Biodiversity, social and cultural services may be proportional to the amount of forest cover remaining, even though some threshold value may exist (i.e. below which some species may not survive and forest services may also no longer be guaranteed).

The challenge for the future is to make forest owners, the forest sector (which needs forest products) and forest users (other than the forest sector, non-market goods and services) aware that forest survival (i.e. as opposed to land degradation due to loss of forest or forest function) probably depends on all of them. It is difficult to decide which is the best way of achieving such a level of awareness: definition of minimum/ maximum thresholds for use of goods and services or implementation of financial incentives for non-market goods such as forest visits by tourists, air quality, carbon storage, water quality, biodiversity…. and wild boar meat for Gallic-like celebrations?

References

Augusto L., Achat D. L., Bakker M. R., Bernier F., Bert D., Danjon F., Khlifa R., Meredieu C. and P. Trichet in press. 2015. Biomass and nutrients in tree root systems–sustainable harvesting of an intensively managed *Pinus pinaster* (Ait.) planted forest. GCB Bioenergy 7: 231–243.

Augusto L, Bakker M. R. and C. Meredieu. 2008. Wood ash applications to temperate forest ecosystems —potential benefits and drawbacks. Plant Soil 306: 181–198.

Augusto L, Bakker MR, Morel C, Meredieu C, Trichet P, Badeau V, Arrouays D, Plassard C, Achat DL, Gallet-Budynek A, Merzeau D, Canteloup D, Najar M and J Ranger. 2010. Is 'grey literature' a reliable source of data to characterize soils at the scale of a region? A case study in a maritime Pine forest in southwestern France. Eur. J. Soil Sci. 61: 807–822.

Bréda N, Huc R, Granier A and E Dreyer. 2006. Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences. Ann. For Sci. 63: 625–644.

Buijs J. 1985. Historia Forestis: Nederlandse bosgeschiedenis. 1985. Vol I: Bosgebruik, bosbeheer en boswetgeving tot het midden van de negentiende eeuw. PhD thesis, Landbouwhogeschool Wageningen.

Carlowitz, H. C. von. 1713. Sylvicultura oeconomica – Anweisung zur wilden Baumzucht, Leipzig, 1713. (Reprint, bearb. von K. Immer u. A. Kiessling, mit einer Einleitung von U. Grober, Freiberg, 2000, p. 84)

Dousseron L. 2006. Quantification physique et chimique de l'effet perturbateur des opérations de gestion sylvicole sur les sols. Master 1 Report, Master Sciences et Technologies, Université Bordeaux 1 et INRA de Bordeaux, 12 pp.

FAO/IUSS. 2006. World Reference Base for Soil Resources: A Framework for International Classification, Correlation and Communication. Report 103, FAO, Rome.

FAO. 2012. State of the World's Forests 2012. 47 p.

GIP ECOFOR. 2010. Gip ECOFOR - Expertise sur l'avenir du massif des Landes de Gascogne.

Jolivet C, Augusto L, Trichet P and D Arrouays. 2007. Les sols du massif forestier des Landes de Gascogne : formation, histoire, propriétés et variabilité spatiale. RFF 59: 7–30.

Kaplan JO, Krumhardt KM and M Zimmermann. 2009. The prehistoric and preindustrial deforestation of Europe. Quaternary Science Reviews 28: 3016–3034.

Mather AS, Fairbairn J and CL Needle. 1999. The course and drivers of the forest transition: the case of France. J. Rural Stud. 15: 65–90.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Mora O, Banos V, Carnus J-M, and M Regolini (Eds). 2012. Le massif des Landes de Gascogne à l'horizon 2050. Rapport de l'étude prospective, Conseil régional d'Aquitaine-INRA, 290 p.

Nachtergaele F, Biancalani R and M Petri. 2012. Land degradation; SOLAW Background Thematic Report 3. 14 pp.

Pongratz J, Reick C, Raddatz T and M Claussen. 2008. A reconstruction of global agricultural areas and land cover for the last millennium. Glob. Biogeochem. Cycle 22: 1–16.

Pottier A. 2013. La forêt des Landes de Gascogne comme patrimoine naturel? Echelles, enjeux, valeurs. PhD Thesis.

Raison RJ, McCormack RJ, Cork SJ, Ryan PJ and NJ McKenzie. 1997. Scientific issues in the assessment of ecologically sustainable forest management, with special reference to the use of indicators. In: Bachelard EP and AG Brown (Eds.), Preparing for the 21st Century: Proceedings of the 4th Joint Conference of the Institute of Foresters of Australia and the New Zealand Institute of Forestry, 21-24 April, 1997, Canberra ACT, Australia.

Sargos J. 1997. Histoire de la forêt landaise. L'horizon Chimérique (Ed.), Bordeaux, France, 559 p.

Trichet P, Bakker MR, Augusto A, Alazard P, Merzeau D and E Saur. 2009. Fifty years of fertilization experiments on *Pinus pinaster* in southwest France: the importance of phosphorus as a fertilizer. For Sci. 55:390–402.

Watkins C. 1993. Forest expansion and nature conservation. In: Watkins C (Ed). Ecological effects of afforestation. Wallingford (UK): CAB International. p 1–13.

Webb NR. 1998. The traditional management of European heathlands. J. Appl. Ecol. 35: 987–990.

Williams M. 2002. Deforesting the Earth: From Pre-History to Global Crisis. Chicago: University of Chicago Press.

Wilson D. 2004. Multi-Use Management of the Medieval Anglo-Norman Forest. Journal of the Oxford University History Society. 1–16.

Soil degradation risks in Basque forests

Nahia Gartzia-Bengoetxea and Ander Arias-González

Climate and soils of the Basque Country

The Basque Country is an autonomous region located in northern Spain. The steeply mountainous terrain in the region connects two great mountain ranges: the Pyrenees and the Cantabrian Mountains. The mountain chain that links these ranges (Aralar, Aizkorri-Urkilla-Elgea, Urkiola, Gorbeia and Sierra Salvada) divides the region into two distinct watersheds: the Atlantic and the Mediterranean. This chain is modest in altitude and is only higher than 1500 m above sea level at a few points very close to the coast, at a maximum distance of about 50-60 km. The valleys in the Atlantic watershed are therefore very narrow and steeply sloping. The mean annual temperature in this watershed is 14-15ºC, the annual precipitation is between 1200-2500 mm, with 200 rainy days, and the number of frost days is well below 20. In contrast, the Mediterranean watershed comprises a series of lower sloping basins that flow into the river Ebro (Fig. 1). The mean annual temperature is 11-12ºC in the Mediterranean watershed, the annual precipitation ranges between 800-450 mm, and the number of frost days is above 40 (Euskalmet, 2014).

The interaction between climatic, geological and topographical conditions in the Basque Country has resulted in a large natural diversity of soils. In the Atlantic watershed, the humid climate and the topographical variations (see Fig. 1) are the most important factors differentiating the soils. Thus, the soils suffer very intense leaching of base cations, and on steep terrain the profiles tend to be rather shallow and poorly developed, in contrast to soils on nearby flatter sites. This complex interaction has resulted in the Atlantic watershed having mostly acidic, rather shallow soils that are very prone to erosion. However, in the Mediterranean watershed, where the climate is drier, calcium carbonate is not leached from the soil and therefore most of the soils are calcareous.

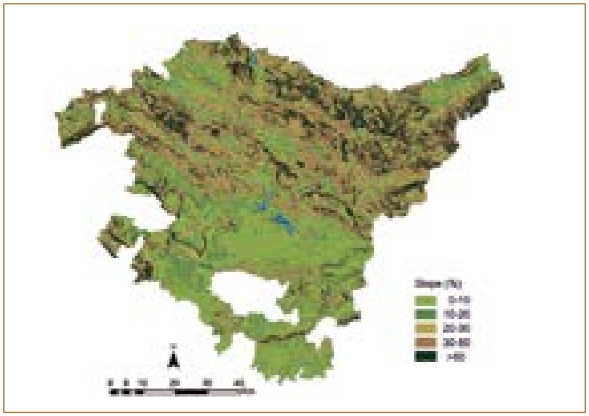

Figure 1. Slope zone map of the Basque Country. The steepest slopes (> 50%) are indicated in dark green and the shallowest slopes in bright green.

The climatic conditions and soil type resulted in very distinctive forest landscapes in the Atlantic and Mediterranean watersheds. The mountains of the Mediterranean watershed were originally covered mainly by *Pinus sylvestris* and *Quercus* spp., although *Corylus, Buxus* and *Acer* were also present. In the southern part of the Basque Country, *Quercus ilex-coccifera* dominated. However, in the Atlantic watershed, the main genera were *Fagus, Quercus (Q. robur and Q. petarea), Fraxinus, Betula* and *Tilia,* with the presence of *Alnus* and *Salix* in wet soils (Michel and Gil, 2013).

Basque forests - a brief forest history

Old-growth primary forests essentially disappeared from the Basque Country in the Middle Ages (Gogeascoechea, 1996). Between the 14th century and the beginning of the 20th century, forests acted as reserves of food and energy and were subjected to rights of usage. They were also greatly affected by the iron industry, which was the main industry in the Basque Country from the Middle Ages onwards. The land in the Atlantic area of the Basque Country played an essential role in the production and marketing of iron in Europe and overseas for the following reasons: (i) the high quality of the iron (mineral) in the region; (ii) the presence of forest cover, essential for making charcoal; and (iii) the proximity to the sea, facilitating transport. The importance of the industry is perhaps reflected by the fact that by around 1590, the word Bilbo was referred to in English as a type of sword made with the iron produced in the region and noted for its temper and elasticity (Bilbo, n.d.) and also as a long iron bar with two sliding shackles, formerly used to confine the ankles of a prisoner (Bilboes, n.d). Indeed, Shakespeare used the term with these meanings in both “The Tragedy of Hamlet, Prince of Denmark” and in “The Merry Wives of Windsor” (Aboutbc, 2012).

As a result of the presence of the iron industry, forests in the Basque Country were cut down and the timber was used to produce charcoal. However, the rate of production was unsustainable as around 2500 kg of beech, holm oak or oak wood was required to produce 100 kg of iron (Corbera, 1998). The first legal text ruling the Charter of the County of Durango, written in 1342, states that forest nurseries existed in Biscay (Quadra Salcedo, 1916). Forest management in the Middle Ages was carried out as follows: the planting distance between oaks was 20 metres (10 metres for walnut trees); after planting, the soil around the trees was dug every two years and fertilised with manure every three years for 12 years and thereafter every five years (Gogeascoechea, 1996). Forests were managed by coppicing and were harvested every 7-8 years to fulfil the charcoal needs of the iron industry. However, in 1332 King Alfonso XI of Castile banned the establishment of new foundries in the Mediterranean watershed to prevent forest degradation (Ruiz Urrestarazu, 2001). This rule also affected the evolution of forest landscapes between the two watersheds.

In addition, the privatization of public forests that took place in the Atlantic watershed in the 19th century as a result of the sale of assets to pay debts incurred by various institutions - mainly because of wars that affected the Basque Country, such as the Convention War (1793-1795), the Peninsular War (1808-1813) and the First Carlist War (1833-1835) - led to deforestation of the Atlantic Basque Country (Michel and Gil, 2013).

As a result of the abovementioned factors, by the end of the 19th century and beginning of the 20th century, forest cover was hugely depleted in the Atlantic watershed. The only trees that remained were chestnut trees, which were a very important source of food for the inhabitants. However, at the beginning of the last century these trees were seriously affected by Cryphonectria parasitica (Murrill) (Chestnut blight) and Phytophthora cinnamon (Rands), which greatly reduced their extension. The forest cover in the region by that time was extremely scarce.

Basque forests in the 21st century

Today the region's forests are shaped by humans through extensive planting. In the last 120 years, forests have mainly been planted with the aim of preventing soil erosion and for production of raw materials. This expansion has brought about good recovery, and forests now cover 55% of the total land area (Fig 2).

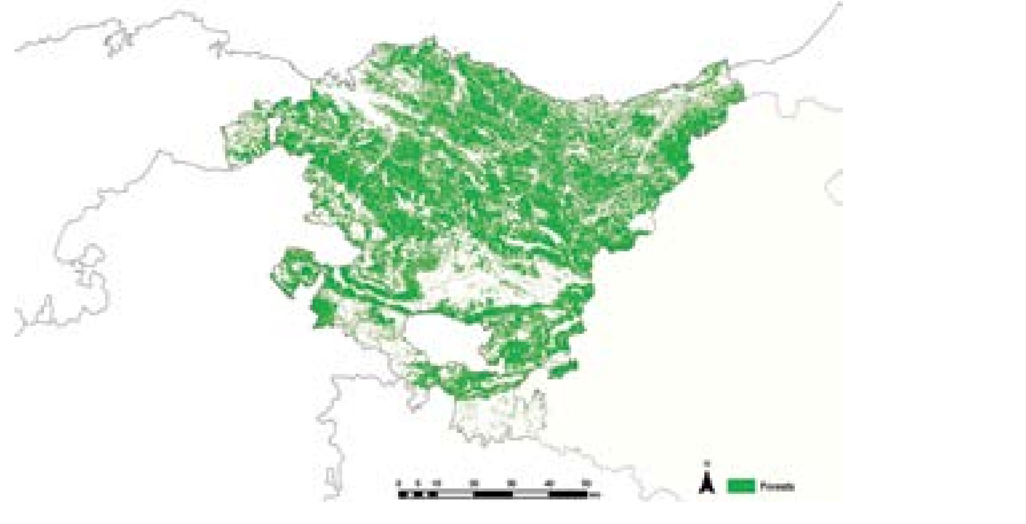

Figure 2. The forest landscape of the Basque Country.

The Atlantic watershed of the Basque Country is characterized by monospecific, even- aged regularly spaced plantations that are managed by clearcutting and systematic thinning regimes. The main species that have been used for afforestation in the region are Douglas fir, larch, black pine, maritime pine, eucalyptus and radiata pine, which together account for almost 90% of the planted forests. At present, commercial forestry in the region is mainly driven by short (eucalyptus) and mid rotation (radiata pine) forestry. *Pinus radiata* is the tree par excellence in the Basque Country, accounting for 63% of the planted forests (IFN4, 2010). The following is a brief description of the commercial forest management applied in the region. The rotation length is around 12-15 years for eucalyptus and around 35-40 years for pines. In both types of plantations, timber is harvested by clearcutting with a chainsaw. In eucalyptus plantations, whole tree harvesting with forest-processors and slash-bundlers is usual. Logs and packed forest residues are left close to the forest road and are collected by forest trucks or forwarders and taken directly to paper mills and/or biomass-based energy production factories - or to a main forest road for further transport. The standard method used for pinewood harvesting is chain-saw cutting and limbing, after which the logs are moved, with the aid of skidders, to a landing area or forest road where they can be collected by trucks for transportation to mills. As *E. globulus* resprouts naturally, site preparation is not necessary in eucalyptus stands until the third generation. Plantation establishment is similar for eucalyptus and pines. In pine stands, site preparation is performed with heavy machinery to clear forest residues and facilitate planting. Subsoiling or ripping is sometimes also carried out to loosen compacted soil. Bulldozers have often been used for site preparation in the region, although foresters are replacing bulldozers with excavators. At present, when excavators are used during site clearance, they are also usually used to dig plantation holes. Although manual site preparation is very uncommon, because of high labour costs, planting is always done by hand.

This type of forestry is very intensive, and inappropriate application of some forestry management activities may lead to soil degradation.

Forest policy

Forest policy is closely linked to the forest history in the Basque Country. Afforestation has been strongly encouraged by the Provincial Councils, and reforestation of deforested slopes has been promoted to prevent the soil erosion that is favoured by the steep terrain. Nowadays, specific laws on the use of heavy machinery are applied in each of the Basque provinces; for instance, in Araba, Provincial Law 11/2007 on forest management and use of resources determines, in Article 32, that the management of forests, forest land and forest resources shall be made according to criteria of sustainable forest management, so that riparian vegetation, the surroundings of wetlands, and water springs are preserved. The use of heavy machinery is prohibited on slopes greater than 30%, and tillage is not allowed in the direction of maximum slope. The legislation also explicitly states that forest operators should avoid compacting or otherwise disturbing the soil. In Bizkaia, the use of heavy machinery is forbidden on slopes > 45% slope, although machinery for making holes is allowed on slopes of up to 60%. However, the legislation explicitly states that these are the maximum slopes allowed and that in adverse weather conditions forest operations should be restricted in order to prevent soil loss and compaction. In Gipuzkoa, the use of spider excavators is recommended for slopes > 35%, although restricted use of bulldozer-type machinery is also allowed. Again, the provincial law mentions that in adverse weather conditions forest operations should be restricted to prevent soil disturbance. In Gipuzkoa, the provincial law has established the following indicators of good work practice: presence of pre-existing natural vegetation after forest operations, unbroken soil structure and no wheel ruts.

Existing policies consider soil as a resource that must be conserved; however, to date, there is no legislation or regulations specifically targeted at soil protection, whether at regional or provincial level. This reflects the lack of awareness of the value of soil protection, as well as the complexity of the subject.

Soil degradation risks

Soil erosion and compaction

Forest roads are essential for providing access for wood extraction; however, road construction is the most expensive and destructive operation in the forest environment as it can lead to soil compaction, increased surface run-off and soil erosion (e.g. Brown *et al.,* 2013). Because of the type of logging system used, the density of forest roads in eucalyptus plantations is usually twice that in pine forests (Fig. 3). As the forests are usually very small, harvestable forests are often surrounded by other forests, which hampers forest operations. This, together with the lack of planning of the layout of road networks to minimize the impact of forest roads in soil and water quality, results in inappropriate forest road networks in the Basque mountains, so that more than 10 % of the forest stand is often occupied by forest roads (see Fig. 3).

In order to evaluate the sensitivity of sites to soil erosion and compaction, the methods outlined in the "Hazard assessment keys for evaluating site sensitivity to soil degrading processes guidebook" published by the British Columbia Ministry of Forests in 1999 have been adapted for southern Europe (Orazio *et al.,* 2014). These are scientifically sound methods of assessing erosion and compaction risks to the soil and climate characteristics of the forests. In the present study, we determined the erosion and compaction risks in 12 plots in the Basque Country (Table 1). Erosion risk was high in 8 of the studied plots, and compaction risk was high or very high in all plots, mainly due to the steep slopes, heavy soil textures and rainy climate. However, the use of appropriate forest management actions helped to minimise damage to forest soil.

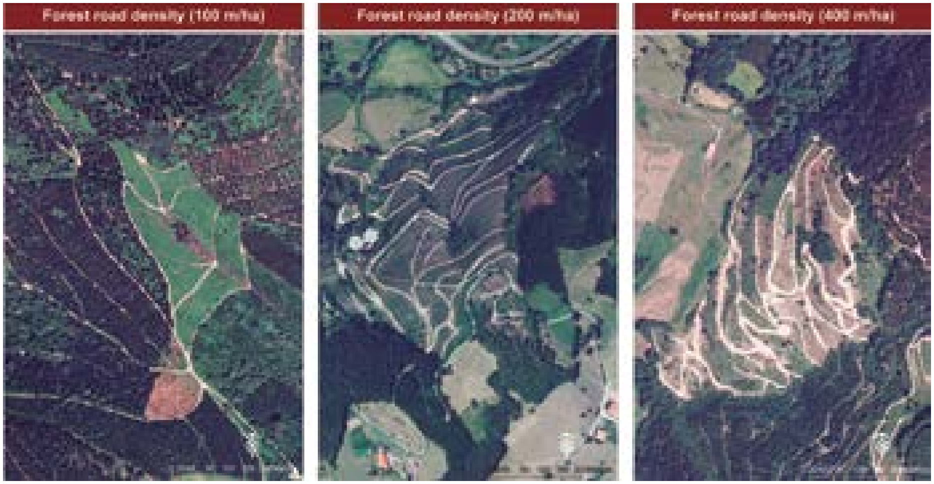

Figure 3. Density of forest roads in pine forest (left), eucalyptus forest (centre) and pine forests with inappropriate forest road networks (right).

Name	UTM_X	UTM_Y	Texture	Slope (%)	Erosion Risk	Compaction Risk
Arbaliza I	483654	4781268	Loam	18	High	High
Arbaliza II	484856	4781044	Loam	14	High	High
Kolitxa	479932	4783301	Loam	29	High	High
La Guinea	481433	4784039	Clay loam	40	High	Very High
La Herbosa I	483205	4785522	Loam	25	High	High
La Herbosa II	483763	4785707	Loam	25	High	High
La Sancha I	481387	4786796	Clay loam	13	Medium	Very High
La Sancha II	481458	4786635	Clay loam	11	Medium	Very High
Aretxabalagane	520125	4792200	Silty clay loam	15	Medium	Very High
Sarasolalde	514000	4776450	Silty clay loam	10	Medium	Very High
Santa Lucia	523300	4795550	Silty clay loam	46	High	Very High
Baluga	488175	4784250	Silty clay loam	25	High	Very High

Table 1. Erosion and Compaction Risks evaluated in 12 plots in the Basque Country

Erosion and compaction risks were assessed in a study area located in the municipality of Zalla (province of Biscay). The plantation was established on a convex hillside with an average slope of 30%. The texture of the soil ranges from silty clay loam to clay, and the average annual precipitation is over 1200 mm. The soil erosion risk was high and the soil compaction risk was very high in this stand.

Three different site preparation techniques were applied after clear cut harvesting in a completely randomized block design: i) down slope ripping, which consists of scalping (see later) and ripping to 50 cm depth following the maximum slope of the stand; ii) scalping, in which the forest residues should be cleared with a front mounted blade without touching the soil, although sometimes the upper centimetres of soil are excavated and slash and surface organic material are displaced to piles down slope; and iii) manual site preparation, i.e. with no machinery.

For each of the treatments, soil loss was monitored for two years in plots of dimensions 30 m x 10 m. The manual site preparation produced almost no sediments while the ripping operation resulted in sediment exports well over 1500 kg/ha/year (Table 2) (González-Arias *et al.,* 2006). Before site preparation, the bulk density of the soil was 1.02 g/cm^3. Manual site preparation resulted in an increase in bulk density, probably due to the skidder traffic through the stand during harvesting (Table 3). However, mechanical site preparation significantly increased the bulk density and also the penetration resistance of the soil, which was above the critical value of about 3 MPa for radiata pine (Sands, *et al.,* 1979) (Table 3), severely restricting root penetration and inducing loss of forest productivity.

Mechanical site preparation also significantly reduced the water infiltration capacity of the soils (Table 3) with a subsequent increase in soil erosion risk (Jansson and Johansson, 1998; Grace *et al.,* 2006) and a reduction in available water content. The heavy machinery used during timber harvesting and mechanical site preparation caused significant soil physical degradation, seriously affecting soil quality.

	Autumn 2002	Spring 2003	Autumn 2003	Autumn 2004	kg/ha/year
Manual	26	0	0	11	19
Scalping	389	1031	631	162	1107
Ripping	423	1273	1136	457	1645

Table 2. Sediments recovered during the two years after site preparation and planting in a *Pinus radiata* plantation in Biscay.

	Bulk density (Mg m^{-3})	Soil Penetration Resistance (Mpa)	Available water content (%)	Saturated hydraulic conductivity (cm h^{-1})
Manual	1.25 (0.0)^{a*}	1.63 (1.48)^{a}	17.9 (0.44)^{a}	3.79 (0.14)^{a}
Scalping	1.50 (0.0)^{b}	3.73 (0.89)^{b}	16.9 (0.11)^{b}	0.46 (0.17)^{b}
Ripping	1.49 (0.81)^{b}	3.23 (0.51)^{b}	15.4 (0.13)^{c}	0.98 (0.36)^{b}

Table 3. Soil physical properties after site preparation and planting in a *Pinus radiata* plantation in Biscay.

Almost all forest soils have the potential to be physically degraded during management operations. In the Basque Country, some basic knowledge (such as soil moisture class map) required for proposal of confident threshold limits for degradation is still lacking. It is therefore difficult to elaborate reliable guidebooks to help managers prescribe and implement sound forest practices that comply with sustainable forest management.

Loss of soil organic matter and soil biodiversity

Soil organic matter (SOM) has long been recognized as an important indicator of soil productivity (i.e. Nambiar, 1996; Carter, 2002). It plays a crucial role in maintaining the sustainability of forest systems by improving soil properties, including physical (structure, bulk density and water-holding capacity) (e.g. Arvidson, 1998; Chenu *et al.*, 2000), chemical (nutrient availability, cation exchange capacity, reduced aluminium toxicity and allelopathy) (e.g. Peinemann *et al.*, 2000) and biological properties (nitrogen mineralization bacteria, mycorrhizal fungi, and microbial biomass) (e.g. Paul and Clark, 1996; Gryndler *et al.*, 2009). Preservation of SOM is crucial to ensure long-term sustainability of forest ecosystems. Calvo de Anta and coworkers (2014) have outlined the concentration of soil organic carbon in northern Spain in a digital map of the topsoil carbon content in the North of Spain (Galicia and the Cantabrian Coast); notably, the concentration of soil organic carbon is lower in the Basque Country than in Asturias and Galicia, probably because past forest management in the Basque Country did not guarantee sustainability and overused the forest.

Forest management is a key factor in controlling organic matter storage in soils. It is therefore important to determine whether the soil C storage capacity is maximal in intensively managed forest soils and, if not, to propose changes in forest management strategies to increase the mitigation capacity and ensure forest sustainability. Carbon saturation refers to the maximum level of C that a particular soil can retain as stabilised soil organic carbon (SOC) based on the physicochemical properties of the soil (Six *et al.* 2002; Stewart *et al.* 2007).

The difference between the theoretical SOC saturation value and the measured SOC of the soil fine fraction corresponds to the soil saturation deficit and may represent the potential for SOC sequestration. Several researchers have tested and validated soil C saturation deficit concept (Hassink, 1997; Stewart, 2008), and we have attempted to use this knowledge to disseminate knowledge of soil C saturation deficit at a regional level (Artetxe *et al.,* 2014).

Figure 4 shows the soil organic carbon saturation deficit calculated on the basis of the protective capacity of the soils for planted forests in Biscay and northern Araba. The zones shown in blue are those with a low saturation deficit (i.e. they are close to saturation with the highest soil organic carbon content), although most planted forests are far from being saturated in soil organic carbon. This is once again probably because past forest management in the Basque Country did not guarantee forest sustainability and led to overuse of the forest. However, the present findings suggest that modern forest management does not appear to have reversed this situation.

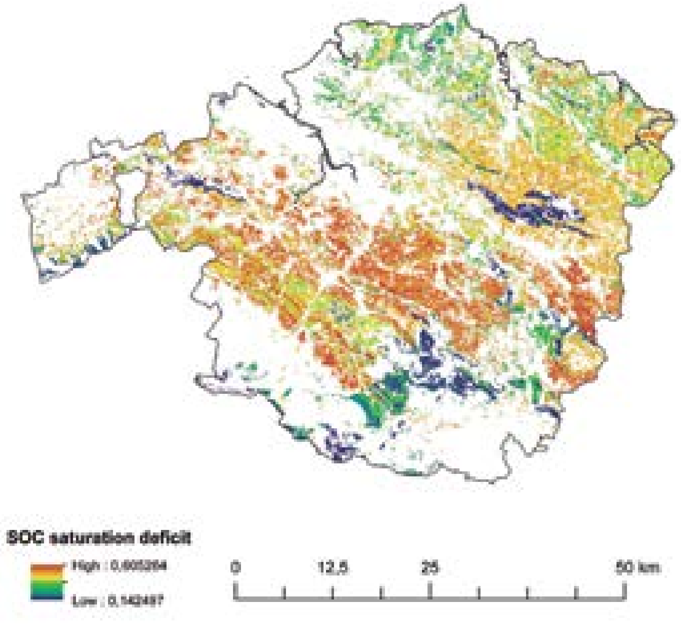

Figure 4. Organic SOC saturation deficit in the northwestern area of the Basque Country.

In plantation forestry, the SOC content increases as the forest grows, because trees are the main source of the carbon. In view of this, we also studied a pine chronosequence to evaluate the effects of mechanized forest operations 3 and 16 years after harvesting and site preparation on soil organic matter structure and dynamics. We compared these mechanized stands with a mature (ca. 40 years) non-mechanized stand, which was established before forest mechanization reached the Basque Country. We observed that forest floor was completely absent after 3 years of site preparation. Even 16 years after mechanized operations, the forest floor content was half of that in the mature forest stand. This huge loss led to a large decrease in fertility of the stand: 200 kg/ha of nitrogen, 7 kg/ha of phosphorus and 25 kg/ha of magnesium were lost as a result of mechanization (Gartzia Bengoetxea *et al.,* 2009b). This is important because phosphorus and magnesium are the most limiting nutrients for tree growth in the Basque Country (Martínez de Arano, 2011). In addition, more than 6 tonnes of carbon per hectare were lost from these stands, which may also have direct implications on climate change. Moreover, a reduction of 300% of the least limiting water range was observed in the 3- year-old plantation relative to the mature stand, and an increase in bulk density (of 125%) was also observed (Gartzia-Bengoetxea *et al.,* 2009a). This may have direct effects on water quality.

The activity and diversity of soil organisms are directly affected by reductions in soil organic matter content. Our past work has revealed a consistent pattern of declining soil carbon concentration and a decline in the abundance of soil fungi relative to bacteria, in association with intensive management in *Pinus radiata* plantations (Gartzia-Bengoetxea *et al.,* 2009a) (Table 4). However, not all soil management practices have a negative impact on soil biodiversity and related services. Although soil compaction and decreased organic matter generally have dramatic effects on soil organisms, by reducing habitats and available nutrients as well as access to water and oxygen, measures such as forest floor conservation, continuous cover forestry instead of clear cutting and long rotations will contribute to improving soil structure, water transfer and carbon storage.

	Pine (40yrs)		Pine (16yrs)		Pine (3yrs)	
0-5 cm						
SOC	53.8	(1.2)	56.8	(1.2)	26.8	(1.6)
Microbial biomass	239.21	(23.72)	304.06	(26.09)	136.51	(4.0)
Bacterial biomass	125.02	(14.11)	159.29	(13.43)	80.64	(1.08)
Gram+	23.59	(0.74)	23.00	(0.39)	34.49	(1.3)
Gram-	26.44	(1.58)	27.75	(0.58)	22.64	(0.35)
G+/G-	0.90	(0.04)	0.83	(0.03)	1.53	(0.08)
fungal	12.85	(2.53)	12.05	(1.13)	3.17	(0.84)
Shannon diversity H	2.65	(0.02)	2.65	(0.02)	2.61	(0.01)
5-15 cm						
SOC	25.7	(2.0)	19.5	(2.5)	20.3	(0.3)
Microbial biomass	185.51	(20.56)	203.71	(27.75)	90.13	(4.52)
Bacterial biomass	99.86	(7.09)	111.20	(14.47)	50.62	(2.86)
Gram+	25.68	(1.8)	24.41	(1.2)	30.91	(0.83)
Gram-	26.71	(0.72)	28.65	(0.91)	23.13	(0.44)
G+/G-	0.96	(0.04)	0.86	(0.06)	1.34	(0.06)
fungal	8.74	(3.47)	5.41	(0.42)	2.99	(0.44)
Shannon diversity H	2.60	(0.01)	2.66	(0.02)	2.71	(0.04)

Table 4: Soil organic carbon (mg C g^{-1} soil), microbial, bacterial and fungal biomass (nmol PLFA g^{-1} soil), Gram-negative and Gram-positive biomarkers (%mole PLFA) and Shannon diversity index H from 0-5 cm and 5-15 cm of the soil profile of a pine chronosequence to evaluate the effect of mechanized forest operations 3 and 16 years after forest operations. Adapted from Gartzia-Bengoetxea *et al.,* 2009a.

Soil sealing

The on-going growth of urban areas leads to increased sealed surface cover, affecting the environment through fragmentation of the landscape, increased surface run-off and obstruction of water infiltration (Vanderhaegen *et al.*, 2015). Land-use change is intrinsically related to both economic development and the ecological characteristics of the landscape. In Spain, between 1975 and 2008, half a million ha of former agricultural land was made available for development (mainly in the most recent years), in parallel with the economic development. Urban sprawl has become the most active driver of desertification in Spain (Barbero-Sierra *et al.*, 2013). In the Basque Country, the rate of soil sealing is also of concern. A comparison of the most recent national forest inventories is shown in Table 5. In the Basque Country, almost 3000 hectares of forest soils and 4000 hectares of productive land have been lost in the last 5 years. To prepare guidelines for land management at regional, national or continental levels, policy makers require suitable spatial and non-spatial information that enables them to assess the state of ecosystems with respect to individual functions and services and to balance trade-off between different land-use options (DeFries *et al.,* 2004). Such information is lacking for the region.

Surface area (ha)	NFI 2010	NFI 2005	
Forest soils	491526	494470	-2944
Agricultural soils	179682	180730	-1048
Sealed soils	45863	41684	4179
Water	5368	5555	
Total	722439	722439	

Table 5. Land use change between the most recent forest inventories (NFI 2010 and NFI 2005) in the Basque Country.

Future perspectives

Societal demands on ecosystem services provided by forests (specifically recreation, carbon sequestration, water quality and passive-use values such as biodiversity) have increased significantly in Europe during the last few decades, and the Basque Country is no exception to this. Moreover, Basque society is changing its habits of consumption and, for example, organic farming is booming. Consumption of local green products, such as wood, is expected to rise in the region. Moreover, renewable energy production systems are increasing in this low carbon economy; energy production based on forest biomass is gaining force in the region, and 60% of the energy produced by renewables is done so through the use of forest biomass. As a result, the pressure on forest plantation systems is increasing, and intensification of commercial forest management is therefore expected. A recent report on the future of the European Forest-based Sector in South-western Europe (Martínez de Arano and Lesgourgues, 2014) suggests that better use of the limited resources is a necessity.

Intensification of forest production in the region should be sustainable and take into account the ecosystem services that forests and forest soils provide. The increased temperature and erratic rainfall that climate change is expected to bring about will make soils increasingly more vulnerable.

Forest managers need to know more about soils, and forest researchers must raise awareness about soils and propose clear and robust recommendations for managers. Innovation and best management practices should be implemented with the help of all stakeholders to meet the desired objective of sustainable intensification. However, research on soil protection and management techniques must also be reinforced in the region.

Forest soils and the associated degradation risks must be taken into account in regional/provincial forest policies. The implementation of a multidisciplinary knowledge-based approach to developing a cross-sectoral soil protection strategy is important. Forest policy should provide incentives for soil protection in the framework of this strategy.

Finally, as most managed forests are privately owned, society in general and the public and private sectors must take measures to ensure provision of all the services demanded of forests.

References

Aboutbc. 2012, December 16th. La relación entre Shakespeare, Tolkien, El Hobbit y Bilbao. Retrieved from http://blog.aboutbc.info/2012/12/16/la-relacion-entre-shakespeare-tolkien-el-hobbit-y-bilbao/ (accessed on 15 November 2014).

Artetxe, A., del Hierro-Cerrezo, O., Pinto-Tobalina, M., Gartzia-Bengoetxea, N., Arias-González, A. 2014. Euskal Autonomia Erkidegoko karbono-hustutegiak. Bahitzeko ahalmena eta horiek sustatzeko neurriak. Eusko Jaurlaritzaren Argitalpen Zerbitzu Nagusia. Vitoria-Gasteiz. pp 212.

Arvidsson, J. 1998. Influence of soil texture and organic matter content on bulk density, air content, compression index and crop yield in field and laboratory compression experiments. Soil and Tillage Research 49, 159-170.

Barbero-Sierra, C., Marques M. J. and Ruíz-Pérez, M. 2013. The case of urban sprawl in Spain as an active and irreversible driving force for desertification. Journal of Arid Environments, 90, 95-102.

B.C. Ministry of Forests. 1999. Hazard assessment keys for evaluating site sensitivity to soil degrading processes guidebook. 2nd ed., Version 2.1. For. Prac. Br., B.C. Min. For., Victoria, B.C. Forest Practices Code of British Columbia Guidebook.

Bilbo. n.d. In Online Etymology Dictionary. Retrieved from http://www.etymonline.com/index.php?term=bilbo&allowed_in_frame=0 (accessed on 15 November 2014).

Bilboes. n.d. In Collins Dictionary online. Retrieved from http://www.collinsdictionary.com/dictionary/english/bilboes (accessed on 15 November 2014).

Brown, K. R., Aust, W.M., McGuirec, K. J. 2013. Sediment delivery from bare and graveled forest road stream crossing approaches in the Virginia Piedmont. Forest Ecology and Management 310, 836-846.

Calvo de Anta, R., Luís, E., Matilla, N., Casás, F., Macías, F., Camps, M., Vázquez, N., Galiñanes, J.M. 2014. Mapa digital de carbono en suelos del norte de España (Galicia y cornisa Cantábrica). In: Macías, F., Díaz-Raviña, M., Barral. M.T. (Eds.) Retos y oportunidades en la ciencia del suelo. Andavira editora. Santiago de Compostela.

Carter, M.R. 2002. Soil quality for sustainable land management: organic matter and aggregation interactions to maintain soil functions. Agronomy Journal 94, 38-47

Chenu, C., Le Bissonnais, Y., Arrouays, D. 2000. Organic matter influence on clay wettability and soil aggregate stability. Soil Science society of America Journal 64, 1479-1486.

Corbera, M. 1998. El impacto de las ferrerías en los espacios forestales. Cantabria (1750-1860). Ería 45, 89-102.

DeFries, R.S., Foley, J.A., Asner, G.P. 2004. Land-use choices: balancing human needs and ecosystem function. Frontiers in Ecology and Environment 2(5), 249-257.

Euskalmet. 2014. Euskal metereologia agentzia. Eusko Jaurlaritza. Retrieved from http://www.euskalmet.euskadi.net/s07-5853x/eu/contenidos/informacion/ana_temperaturas/eu_7278/eu_temperaturas.html (accessed on 15 November 2014).

Gartzia-Bengoetxea, N., González-Arias, A., Kandeler, E., Martínez de Arano, I. 2009a. Potential indicators of soil quality for temperate forest ecosystems: A case study in the Basque Country. Annals of Forest Science 66, 303-313.

Gartzia-Bengoetxea, N., González-Arias, A., Martínez de Arano, I. 2009b. Effect of tree species and clear-cut forestry on forest floor in adjacent temperate forests in northern Spain. Canadian Journal of Forest Research 39, 1302-1312.

Gogeascoechea, A. 1996. Woodland and forest uses in old laws of Biscay. Vasconia 24, 101-114.

Gonzalez-Arias A, N. Gartzia-Bengoetxea, M. Onaindia, I. Martinez de Arano. 2006. The effect of site preparation on water and soil protection in Pinus radiata plantations in the Basque Country. Ecosystem Goods and Services from Planted Forests. International Congress on Cultivated Forests.

Grace, J.M., Skaggs, R.W., and Cassel, D.K., 2006. Soil physical changes associated with forest harvesting operations on an organic soil. Soil Science Society of America 70, 503-509.

Gryndler, M., Hrselová, H., Cajthaml, T., Havránková, M., Rezácová, V., Gryndlerová, H., Larsen, J. 2009. Influence of soil organic matter decomposition on arbuscular mycorrhizal fungi in terms of asymbiotic hyphal growth and root colonization. Mycorrhiza 19, 255-266.

Jansson, K., Johansson, J. 1998. Soil changes after traffic with a tracked and a wheeled forest machine: a case study on a silt loam in Sweden. Forestry 71, 57–66.

Martínez de Arano, I. 2011. Estado nutritivo y recomendaciones de fertilización para el pino radiata. Euskadi Forestal nº 61.

Martínez de Arano, I., Lesgourgues, Y. 2014, Sout-Western European Outlook. In Hetemäki, L. (eds) Future of the European Forest-Based Sector: Structural Changes towards Bioeconomy, European Forest Institute (EFI), Joensuu. pp. 84-94.

Michel, M., Gil, L. 2013. La transformación histórica del paisaje forestal en la Comunidad Autónoma de Euskadi. Colección Lur nº 18. Eusko Jaurlaritza-Gobierno Vasco. Vitoria-Gasteiz.

Nambiar, E.K.S. 1966. Sustained productivity of forests is a continuing challenge to soil science. Soil Science Society of America Journal 60, 1629-1642.

Orazio, C., Fermet-Quinet, S., Branco, M., Vilas-Boas, L., Almeida, M.H., Madeira, M., Abrantes, G., Tomé, M., Palma, J., Soares, P., Araújo, C., Reis, A.R., Ferreira, L., Leal, L., Hevia, A., Majada, J., Álvarez-González, J.G., González-Ferreiro, E., Prendes, C., Canga, E., Ruiz-González, A.D., Gartzia-Bengoetxea, N., Moragues-Saitua, L., Arias-González, A., Blanco, F., Cantero-Amiano, A., Régolini, M., Meredieu, C., Gardiner, B., Dutech, C., Jactel, H., Bernier, F., Labbé, T., Lung-Escarmant, B., Labbé, F., Kamimura, K., Capdevielle, X., Bert, D., Castro, A., Maris, C., Morin, J., Didolot, F., Picard, O., Mathieu, P., Drenou, C., Fraysse, J. Y., Alazard, P., Chevereau, M., Rousseau, J.P., Michaud, D., Eisner, N., Lapeyre, P., Cailly, P., de Boisseson, J.M., Lario, F.J. 2014. Integrated Risk Management in Planted Forests. FORRISK Technical Guide. Pierroton.

Paul, E.A., Clark., F.E. 1996. Soil microbiology and biochemistry. 2nd Edition. Academic Press. California, USA.

Peinemann, N., Amiotti, N.M., Zalba, P., Villamil, M.B. 2000. Effect of clay minerals and organic matter on cation exchange capacity of silt fractions. Journal of Plant Nutrition and Soil Science 163, 47-52.

Quadra Salcedo, F. de la. 1916. O.c. Fuero Viejo 1503, título 2, ley 2 p. 159-160. El Fuero Viejo de Vizcaya 1452. O.c. capítulo 40, p. 39

Ruiz Urrestarazu, M. M. 2001. Montes y bosques vascos. Euskonews & media 108, 1-26.

Sands, R., Greacen, E.L, Gerard, C.J. 1979. Compaction of Sandy Soils in Radiata Pine Forests. I A Penetrometer Study. Australian Journal of Soil Research 17, 101-113.

Vanderhaegen, S., , Koen De Munter, K., Canters, F. 2015. High resolution modelling and forecasting of soil sealing density at the regional scale. Landscape and Urban Planning 133, 133-142.

Soil degradation in Galicia

Nieves Barros, María José Rozados and Margarita Alonso

Introduction

Forests occupy 68.96 % of the land in Galicia (NW Spain), which is characterized by a mild Atlantic climate. Most of the rest of the land is under pasture destined for feeding cattle.

The importance of forest land in sequestering carbon (C), highlighted by the EU in 1992 promoting the afforestation of marginal agriculture land, has strong repercussions in Galicia. The European Union's policy of granting subsidies for afforestation is indirectly enhancing abandonment of agricultural land and afforestation of good quality agriculture land rather than of marginal land. As a result, large areas of agriculture land have been afforested (García-Campos *et al.* 2010) and Galicia is now one of the major forest regions in Europe, surpassed only by Finland and Sweden (Marey *et al.* 2006).

Forestry holds a special position in Galicia because of the extensive woodland cover and the increasing concentration of fast growing tree species for the wood industry and biomass production for renewable energy. The exploitation model, which is based on the use of fast growing tree species, is an important factor affecting soil quality.

Forestry management in Galicia faces an important challenge regarding the development of a sustainable exploitation model that takes into account the impacts on soil. The main obstacle is the unfavorable structure of Galician forestry wherein 97 % of the forest land is comprised by scattered privately-owned small holdings. This has led to poor development of the sector and difficulties in promoting sustainable forest management (SFM) that takes into account soil quality (Ambrosio, 2006).

Forestry is considered to be underdeveloped in Galicia: forest production could be increased and used as a driver of regional and rural economic development. It is therefore important to formulate new strategies, policies and processes on the basis of SFM (Xunta de Galicia 2001), particularly now that a new strategy focusing on energetic biomass production has been launched. SFM involves considering the impact of forest management on soil quality and productivity, as defined by the concepts of carbon sequestration capacity and C turnover, which go further than quantitative measures of C content and consider the nature of the SOM and its chemical, physical and biological stabilization as important factors determining C capture and turnover (Chen *et al.* 2004; Herrmann *et al.* 2014).

The high incidence of forest fires is another important cause of soil degradation in Galicia and is considered to be an indirect result of a misguided forestry policy and structural problems (Held and Küpper, 2001). Between 1996 and 2005, the annual average number of fires in Spain was 20.887. Of these, 60% were deliberate and 50 % took place in Galicia (Bisquert *et al.* 2014).

This report aims to summarize the status of soil degradation in Galicia, and how this is influenced by the main management practices used in the region, as well as to encourage the implementation of new strategies and procedures that contribute to sustainable soil management.

Soil organic matter (SOM) and land use in Galicia

It is generally accepted that variations in SOM and C contents are associated with soil quality and increases/ decreases in soil fertility. This is the main reason underlying attempts to establish C stocks worldwide by development of a soil database.

Galician soils are characterized by intermediate to high C contents, in the map of organic carbon in topsoils in Europe (Jones *et al.* 2003). The organic matter in Galician soils is also considered to be stable as a result of the generally low soil pH, presence of Al-humus complexes, the specific climatic parameters, and in particular the hydric balance in each location (Rodriguez-Lado, 2014). When studying the C sequestration capacity associated with certain management practices in Galicia, it is therefore important to take into account the initial high C contents of the soil and that the stable organic matter has characteristics that are specific to particular locations.

It has recently been reported that changes in SOM properties and C turnover may be highly dependent on high or low C contents and on soil microbial structure and diversity, and that SOM properties may depend on the C levels rather than the type of management under study (Peltre *et al.* 2014; Lerch *et al.* 2013). This may affect the inclusion of Galician soils in global models of SOM and C changes, and it is therefore important to carry out regional studies that contribute to a better understanding of SOM properties and how they vary in relation to soil management. For example, it is widely considered that transformation of land to agricultural use enhances C loss, while afforestation of agriculture land contributes to C sequestration in soil (Jones *et al.* 2004). However, the same conclusions were not reached in this type of study in Galicia. Comparative studies of agricultural and afforested land have not shown remarkable differences or general trends in relation to C contents, SOM properties or C turnover through microbial activity (García-Campos *et al.* 2010; Pérez-Cruzado *et al.* 2014; Barros *et al.* 2014a).

In this sense, the most remarkable finding has been that afforestation of agricultural land in Galicia is followed by a period characterized by loss of large amounts of the initial C content, of up to 50-60 %. The duration of C loss depends on the tree species involved. At the end of the rotation of each tree species, soil C sequestration may vary from partial to net gains (Pérez-Cruzado. 2014). The initial results strongly suggest that afforestation should include management actions aimed at minimizing the initial strong loss of C and taking into account the duration of the rotation, to improve the C sequestration capacity. Most of these studies used quantitative C data and did not take into account the role of the type of SOM in the capacity of the soil to retain C. This has led to a worldwide effort to determine the SOM macromolecule structure and the introduction of the concept of SOM or C stabilization mechanisms in C sequestration studies. This effort also affects soil research in Galicia and it is applied to the main factors influencing SOM: land use management and forest fires. Study of changes in SOM on the basis on SOM properties also involves the use and evaluation of new techniques. Figure 1 shows an example of how SOM evolves in two chronosequences in Galicia under different tree species.

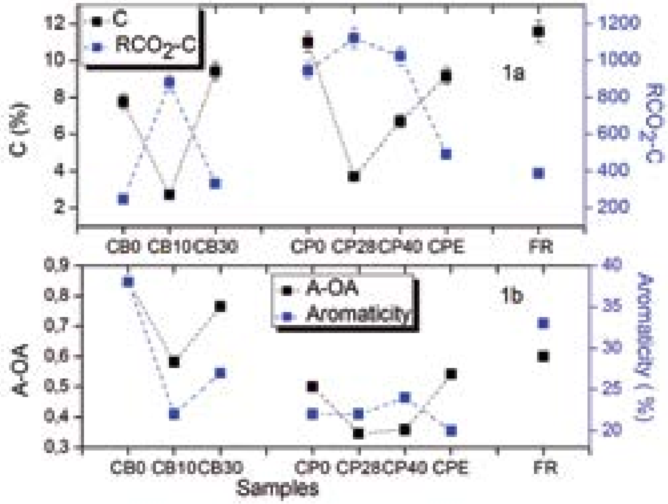

Figure 1: Temporal changes in C contents and C mineralization rates (RCO_2-C in picomol CO_2 g^{-1} C s^{-1}) (1a), percentage of Aromaticity and degree of SOM degradation (A-OA) (1b) in two chronosequences, CP and CB, under Pinus radiata, and in two pasture precursors (CB0 and CP0), a Eucalyptus nitens stand at the end of the rotation period (18 years, CPE) and a reference forest plot (FR) with no prior history of afforestation. In CB and CP, 50-60 % of the initial C was lost, 10 and 28 years after afforestation, respectively. At the end of the rotation (CB30, CP40 and CPE) soils showed partial to net C gains, depending on the chronosequence. The only factor contributing to partial or net C gains was the initial SOM nature, which is more aromatic and with a higher degree of degradation in CB0 (net C gains) than in CP0 (partial C gains). The aromaticity percentage and A-OA ratio were determined by ^{13}C-CPMAS, while CO_2 dissipation rates were determined by calorespirometry.

The results of some such studies have shown that the C sequestration capacity may be affected by additional factors such as the initial nature of the SOM in the converted land, together with prior soil management (Barros *et al.* 2014b; Fernández-Nuñez *et al.* 2010), soil microbial structure and metabolic activity (Herrmann *et al.* 2014) and the physical, chemical and biological mechanisms of SOM protection (Peltre *et al.* 2014). These features have not been well explored in Galicia yet.

Effects of silvicultural practices: thinning

In natural woodlands, the intensity of thinning has an important impact on soil conservation. These natural areas must be preserved against fire, erosion and degradation. Regeneration, understory biomass and species diversity may be severely modified by thinning. Woodland areas are traditionally structured as coppice woodland, surrounded by pastures and orchards with occasional removal of some trees for fuel by local inhabitants. Some areas are used for game hunting, mainly roe deer and wild boar, and recreational use is also common. Some woodlands are managed as silvipastoral systems with low densities of livestock (mainly cattle and horses). A good equilibrium can be achieved by use of the land for different purposes.

Although woodlands are often privately owned, the land is sometimes collectively owned and managed as a neighborhood forest in a model that is still typical in Galicia. The common forest land is owned by all members of a parish. Each citizen owns a percentage of the indivisible forest area and the management must be agreed on with all the members of the community by common consent. In studies carried out in the Atlantic area of Galicia, short and intermediate temporal effects on forest soil composition have been found to depend on thinning intensity in Quercus robur stands (Alonso *et al.* 2005, 2008, 2009). After application of the treatments, fallen trees were left in the plots. Two years after thinning, only forest soil reflected any changes in comparison with unthinned control plots, and the mineral soil was not affected by thinning (Alonso *et al.* 2005). The main difference observed in the forest soil, in plots in which the intensity of thinning was high, was an increase in concentrations of carbon and nitrogen (Table 1). Six years after intense thinning, the redox potential had increased in the upper 20 cm soil layer, thus enhancing the oxidant conditions due to increased exposure to solar irradiation during summer (Alonso *et al.* 2008). During the winter, 8 years after treatment, the water content and concentrations of carbon, nitrogen and tannins were higher in the humus layer of the intense thinned plots than in control ones (Alonso *et al.* 2009).

It is generally recommended to reduce the initial basal area by less than 55%, preferably less than 35%, by thinning. Reductions of 15% and 35% did not have any effects on either forest soil or on mineral soil until 8 years after thinning (Alonso *et al.* 2009).

		Thinning level (% woodland basal area reduction)			
Forest soil		0	15	35	55
L+F layer	C (%)	51.99±4.15 b	53.42±2.63 ab	52.89±3.58 ab	54.22±2.41 a
	N (%)	1.681±0.268 b	1.696±0.226 b	1.674±0.250 b	1.851±0.235 a
H layer	C (%)	35.79±7.96 b	36.58±9.22 b	35.61±9.71 b	42.26±8.67 a
	N (%)	1.434±0.281 b	1.445±0.284 b	1.419±0.300 b	1.644±0.280 a

Table 1.- Mean concentrations of carbon and nitrogen (± standard deviation), on a dry weight basis, in forest soil (L+F) and H layers, during the two years following thinning treatments in Q. robur stands. Values indicated by different small letters in the same row are significantly different Duncan's test, $p < 0.05$).

Effects of forest fires

Forest fires are often devastating events that affect species diversity and human life and also lead to soil degradation and erosion. Galicia is particularly susceptible to forest fires, and the effects on Galician wildlife have been widely studied. Galician fire prevention plans aim to address public awareness and to plan and organize forestry and agricultural spaces, infrastructures, silvicultural treatments, preventive vigilance, fire detection and fighting (Xunta de Galicia 2007).

The effects of fire on soil, SOM and soil microbial structure have been widely studied as a result of the serious effects of fire on the Galician economy. Numerous excellent reports on the effects of fire on soil have been published by Galician research groups at the three Universities and Galician research institutes, supported by subsidies from local and national governments. The knowledge compiled is of great help in providing a clear picture of the challenges involved in preventing or minimizing fires in Galicia.

The impact of fire on soil depends on the fire severity, which can be defined on the basis of the temperature reached (Fernández *et al.* 1997; Cancelo-González *et al.* 2012). Attempts have been made to relate fire severity to visual signs at the soil surface and in the organic cover in order to define the level of erosion (Fernández *et al.* 2010; Merino *et al.* 2014). Erosion is the most important type of damage to soil as it involves loss of SOM and nutrients (of up to 30-60 % of the initial C depending on the fire severity) (Fernández *et al.* 1997; Merino *et al.* 2014). Rapid diagnosis of fire severity enables design of the most appropriate post-fire treatments to minimize soil damage (Fernández *et al.* 2011).

The high C contents of Galician soils and the large amounts of C lost as a result of fires, subsequently released to the atmosphere as CO_2, have an enormous impact on global warming. Fire also affects the SOM chemical and biological nature. Cellulose and hemicellulose contents decrease immediately after burning, while lipids do not vary. Humic acids also decrease, but humin and also OM bound to Al and Fe increase. Enhancement of C mineralization through post fire microbial activity has also been reported (Fernández *et al.* 1997). During forest fires, rearrangement of C forms occurs and refractory and resistant organic C forms, including black carbon, are formed "de novo". As a consequence, OM turnover is altered, thus affecting the global C balances reported for global warming assessment, which should be recalculated accordingly (González- Pérez et al. 2004). This concept has been overlooked in Galicia despite the high impact of fire in the region.

Future prospects

Soil degradation is a persistent problem worldwide. No continent, country or region is free of the problem. Soil is therefore of critical importance, as recognized in the phrase No Soil, No Life (Land degradation. http://www.globalchange.umich.edu). Galicia must therefore continue to develop policies aimed at maintaining soil quality.

With respect to forestry management, it is important to control soil compaction and, in the case of land used for energetic biomass production, to remedy the inherent C loss by the addition of appropriate fertilizers (Merino. 2008). Erosion and its consequences on water quality must be prevented by suitable selection of land for afforestation, and in the case of fires, by adequate post-fire treatments developed on the basis of fire severity, type of soil and properties of the terrain affected.

It is of upmost importance to maintain and even to improve soil fertility. For this purpose, it is crucial to monitor the organic C pools across landscape units and over time, to enable assessment of spatial and temporal organic C pools and fluxes, and to obtain reference data to enable evaluation of soil management practices and/or treatments. This also requires investment in technological development to improve our knowledge of SOM properties in Galicia and of the associated microbial biomass structure. It is therefore important to investigate and provide alternative methods to improve the sensitivity and indices of C nature and fluxes to help us understand the relationships between SOM nature, SOM biodegradability and microbial diversity. This is possible through the application of emerging methods such as Thermal Analysis, Calorimetry or ^{13}C CPMAS, which have recently been used with promising results regarding the macromolecule composition of SOM and its biodegradability (Merino *et al.* 2014; Barros *et al.* 2011; Herrmann *et al.* 2014).

The material, human resources and scientific infrastructure in Galicia are sufficient to allow this autonomous region to continue innovating in research addressing soil degradation.

References

Alonso, M.; Ignacio, M.F.; Nuñez, M.; Rozados, M.J.; Silva, F.J.; Fontúrbel, M.T. 2005. Cambios a corto plazo en el nivel de algunos parámetros edáficos y foliares después de una clara en una masa de *Quercus robur* L. en Galicia, NO de España. Cuadernos de la Sociedad Española de Ciencias Forestales 20: 47-54.

Alonso, M.; Ignacio, M.F.; Rozados, M.J.; Fontúrbel, M.T.; Silva, F.J. 2008. Potencial redox de la fase líquida del suelo y niveles de clareo en una población natural de *Quercus robur* en Galicia, NO de España. Cuadernos de la Sociedad Española de Ciencias Forestales 25: 55-59.

Alonso, M; Rozados, M.J; Ignacio, M.F; Silva-Pando, F.J.; Fontúrbel, M.T. 2009. Cambios a medio plazo en el nivel de algunos parámetros edáficos y foliares después de una clara en una masa de *Quercus robur* L. en Galicia, NO de España. Actas 5º Congreso Forestal Español 5CFE01-239: 2-11.

Ambrosio, Y. 2006. La certificación forestal en Galicia. CIS madeira: Revista do centro de innovación e servizos tecnolóxicos da madeira en Galicia. ISSN 1886-3752 Nº 14: 70-83.

Barros, N.; Feijoo, S.; Hansen, L.D. 2011. Calorimetric determination of metabolic heat, CO_2 rates and the calo-respirometric ratio of soil basal metabolism. Geoderma 160: 542-547.

Barros, N.; Martín-Pastor, M.; Pérez-Cruzado, C.; Merino, A. 2014a. Emerging methods to assess C sequestration based on SOM nature in afforested lands: application of ^{13} C CPMAS and Thermal Analysis. JRC Science and Policy Reports, DOI: 10.2788/17815.

Barros, N.; Pérez-Cruzado, C.; Martin-Pastor, M.; Merino, A. 2014b. Changes in soil organic matter in a forestry chronosequence monitored by thermal analysis and calorimetry. Spanish Journal of Soil Science 4: 239-253.

Bisquert, M.; Sánchez, J.M.; Caselles, V. 2014. Modelling fire danger in Galicia and Asturias from MODIS Images. Remote Sensing 6: 540-554.

Cancelo-González, J.; Rial-Rivas, M.E.; Barros, N.; Díaz-Fierros, F. 2012. Assessement of the impact of soil heating on soil cations using the degree-hours method. Spanish Journal of Soil Science 2: 32-44. DOI: 10.3232/SJSS.2012.V2.N3.04.

Chen, C.R.; Xu, Z.H.; Mathers, N.J. 2004. Soil Carbon pools in Adjacent Natural and Plantation Forests of Subtropical Australia. Soil Sci. Soc. Am. J. 68: 282-291.

Fernández, I.; Cabaneiro, A.; Carballas, T. 1997. Organic matter changes inmmediately after a wildfire in an atlantic forest soil and comparison with laboratory soil heating. Soil Biology and Biochemistry 29 : 1-11.

Fernández, C.; Vega, J.A.; Vieira, D.C.S. 2010. Assessing soil erosion after fire and rehabilitation treatments in NW Spain: performance of RUSLE and Revised-Morgan-Finney models. Land Degradation and Development 21: 74-87.

Fernández, C.; Vega, J.A.; Fontúrbel, M.T. 2011. Effectiveness of three post-fire treatments at in reducing soil erosion in Galicia (NW Spain). International Journal of Wild-land Fire 20: 104-114.

Fernández-Núñez, E.; Rigueiro-Rodríguez, A.; Mosquera-Losada, M.R. 2010. Carbon allocation dynamics one decade after afforestation with *Pinus radiata* D. Don and *Betula alba* L. under two stand densities in NW Spain. Ecological Engineering DOI 10.1016/j.ecoleng_2010.03.007.

García-Campos, E.; Zorita, F.; Gil-Sotres, F.; Leirós, M.C.; Trasar-Cepeda, C. 2010. Preliminary results on the effects of afforestation of maize soils with *Populus alba* L on carbon metabolism. Geographical Research Abstracts, vol 12, EGU General Assembly 2010: 5299.

González- Pérez, J.A.; González-Vila, F.J.; Almendros, G.; Knicker, H 2004. The effect of fire on soil organic matter - a review. Environmental International 30: 855-870.

Held, T.; Küpper, K.M. 2001. Unsustainable forestry causes forest fires. A case study from Galicia (NW Spain). Geographica Polonica 74: 65-76.

Herrmann, A.; Coucheney, E.; Nunan, N. 2014. Isothermal microcalorimetry provides new insight into terrestrial carbon cycling. Environmental Science and Technology, DOI 10.1021/es403941h.

Jones, R.J.A.; Hicderer, R.; Rusco, E.; Loveland, P.J.; Montanarella, L. 2004. The map of organic carbon in topsoils in Europe: version 1.2 (September 2003). Special publication Ispra Nº 72 S.P.I.04.72.

Lerch, T.Z.; Coucheney, E.; Herrmann, A. M. 2013. Sensitivity of soil microbial catabolic profiles to a gradient of carbon inputs: Does the soil organic matter matter? Soil Biol. Biochem. 57: 911-915.

Marey Perez, M.F.; Rodríguez, V.; Crecente Maseda, R. 2006. Using GIS to measure changes in the temporal and spatial dynamics of forestlands: experiences from north-west Spain. Forestry 79(4): 409-423 doi: 10.1093/forestry/cpl027.

Merino, A. 2008 Extracción de biomasa en los suelos forestales, principales variables a tener en cuenta para evitar la degradación del suelo. Cuad. Soc. Esp. Cienc. For. 25: 23-32.

Merino, A.; Ferreiro, A.; Salgado, J.; Fontúrbel, M.T.; Barros, N.; Fernández, C.; Vega, J.A. 2014. Use of thermal analysis and solid-state ^{13}C CP-MAS NMR spectroscopy to diagnose organic matter quality in relation to burn severity in Atlantic soils. Geoderma 226-227: 376-386.

Peltre, C.; Fernández, J.M.; Craine, J.M.; Plante, A.F. 2014. Relationships between biological and thermal indices of soil organic matter stability differ with soil organic carbon level. Soil Science Society of America Journal 77: 2020-2028.

Pérez-Cruzado, C.; Sande, B.; Omil, B.; Rovira, P.; Martín-Pastor, M.; Barros, N.; Salgado, J.; Merino, A. 2014. Organic matter properties in soils afforested with *Pinus radiata.* Plant and Soil: DOI 10.1007/s11104-013-1896-5.

Rodríguez-Lado, L. 2014. Influence of climatic parameters in the carbon content of topsoils in Galicia (NW Spain) Geophysical Research Abstracts, vol. 16: 13750, EGU General Assembly 2014.

Xunta de Galicia, 2001. O Monte Galego en cifras. Dirección Xeral de Montes e Industrias Forestais. Consellería de Medio Ambiente. Xunta de Galicia.

Xunta de Galicia, 2007. Ley 3/2007, de 9 de abril, de prevención y defensa contra los incendios forestales de Galicia; Consellería de Medio Rural y del Mar, 2013. Available on line: http://www.medioururalemar.es/fileadmin/arquivos/publicacions/2013/LeiDeIncendios/cast/Ley_03-07_de_prevenc_y_defensa__contra_los_incend_castellano_.pdf (accessed on 31 December 2013).

Soil degradation risks and prevention measures in planted forests. The case of eucalyptus plantations in Portugal

Manuel Madeira and Clara Araújo

Abstract

An overview of the soil degradation risks in areas of Portugal where eucalyptus plantations are managed intensively as coppice stands is presented. Several studies have indicated that carbon and nutrient losses and soil compaction in such plantations are mainly associated with soil and harvest residue management practices. It has also been concluded that experimental results obtained at plot level, for one rotation period, are very useful for identifying and establishing valid options for soil and organic residue management to avoid soil degradation and therefore to ensure soil functional processes and forestry productivity and sustainability. However, such data do not take into account long-term effects or the risk of soil degradation in plantations due to activity at the management scale. Therefore, long-term experimental systems and risk assessment systems must be developed and soil quality monitoring systems must be established and implemented to help control soil degradation processes (e.g. erosion, compaction, nutrient and carbon losses) at the plantation management unit scale.

Introduction

Most planted forests in Portugal are eucalyptus (*Eucalyptus globulus* Labill.) plantations, which at present cover about 820,000 ha of land in the country. Most of the large scale establishment of eucalyptus plantations occurred up until the end of the 1980s and mainly involved the use of existing forest land and degraded agricultural land (Costa *et al.,* 2014). In Portugal, eucalyptus plantations are established on flat to strongly undulating land; the soils are developed on schists, granites and sedimentary rocks and are mainly Regosols, Cambisols, Luvisols, Umbrisols and Arenosols.

The expansion of eucalyptus plantations has led to increased awareness about the effects on changes in soil quality (acidification, organic carbon and nutrient losses, soil fertility loss, erosion) caused by the intense biomass removal and perturbations associated with plantation establishment practices (e.g. deep ploughing, ripping, harrowing) and harvesting. It is essential to analyze whether eucalyptus plantations contribute to soil degradation and whether management systems ensure provision of sustainable productive, environmental and economic functions.

It is well known that soil loss is minimal in the land below undisturbed forests. In fact, forests prevent soil degradation, and forest plantations have been established throughout the world with the aim of preventing soil erosion due to water and wind. However, accelerated erosion may be a serious problem in forested land, because the rates of soil loss may be quite high and also because huge areas of land are often involved (Brady & Weil, 2008). Therefore, soils in intensively managed forest plantations may be threatened if adequate management practices are not implemented. In the last four decades, it has been shown that the presence of eucalyptus plantations can lead to important changes in physical (bulk density, compaction, aggregation stability, hydraulic conductivity and infiltration rate) and chemical (organic matter concentration, soil reaction and nutrient availability) soil conditions (Madeira & Fabião, 2012). In Portugal, large areas of eucalyptus plantations are established on undulating or strongly undulating relief with a high potential for erosion-related problems. In addition, the inappropriate use of heavy machinery for installation and exploitation of such plantations may lead to soil degradation, e.g. "accelerated" erosion, compaction, soil organic matter loss and loss of biodiversity. Accelerated erosion is of great concern for foresters and for society in general because it causes both on-site impacts (soil loss, nutrient loss, decreased productivity) and off-site impacts (reduced water quality, increased sedimentation, habitat loss). It is also a serious economic problem. Soil compaction often occurs when heavy machinery is used on wet soils. It can lead to changes in ecosystem function by reducing the water infiltration capacity, thus increasing the risk of erosion through accelerated run-off, and also by hindering root development/expansion, thus affecting the productivity of plantations (B.C. Ministry of Forests, 1999).

Soil degradation processes are expected to be more important during the inter-rotation period, i.e. the period between harvesting and the establishment of a new plantation. During this period, accelerated erosion and compaction may be exacerbated by loss of tree cover and, in commercial forestry, by the use of heavy machinery for harvesting and site preparation. Soil perturbation may also enhance the loss of nutrients and organic C. In this context, correct management practices are very important to avoid undesirable effects derived from erosion and compaction. It is therefore essential to develop and apply methods of evaluating soil degradation risks, to provide forest managers with tools for planning forest operations, such as harvesting and site preparation, while avoiding erosion and compaction. Such tools may enhance forest productivity and lead to protection of forest soils and water resources. It is therefore essential to address the challenges associated with soil degradation processes, environmental quality and sustainability of intensive forestry at the forest management scale.

Soil nutrient status

Evaluation of soil nutrient status in former eucalyptus (mostly *Eucalyptus globulus* Labill.) plantations, at the end of second and third rotations, relative to those observed in low perturbed forest systems (open forest of *Quercus suber* L. and plantations of *Pinus pinaster* Ait.) revealed a trend towards acidification associated with strong losses of non acidic cations (mostly calcium and magnesium) and an increase in exchangeable aluminium (Madeira, 1986 and 1989).

Such losses were attributed to huge amounts of nutrients being accumulated in the aboveground biomass and in the litter layer of the forest floor. This is supported by the negative annual nutrient balances in eucalypt plantations (in contrast with other forest systems) as the annual flux from the soil to the biomass is higher than the respective return to the soil (litterfall, throughfall) plus withdrawal (Madeira & Fabião, 2012), which leads to short term decreases in the concentration of exchangeable non acidic cations (Madeira *et al.,* 2012). However, the intensity of such changes is strongly associated with the soil nutrient status. Thus, in accordance with the wide variability in site characteristics under Mediterranean conditions, the responses of eucalyptus plantations are either similar to or very different from those reported for similar plantations growing in a wet tropical climate. Therefore, decisions regarding the intensity of biomass removal (trunk only or whole-tree harvest) from eucalyptus plantations should take into account the specific "soil compartment" associated with the amounts of nutrients available in soil and with the respective recovery capacity.

Other studies have shown that management practices associated with soil perturbation (Figure 1) during establishment of eucalyptus plantations also lead to large losses of nutrients. For instance, it was observed that

Figure 1. Soil perturbation by harrowing (left) and by ripping after harrowing (right) for replanting eucalyptus after slash and stump removal.

the conventional soil preparation (e.g. ploughing plus harrowing) used during establishment of new forest plantations may lead, at the beginning of the rotation, to a strong depletion of non acidic cations and available P (Madeira *et al.,* 1989), without recovery to the initial concentration during the rotation period (Madeira *et al.,* 2002a). Therefore, important changes in nutrient soil status observed in former eucalyptus plantations should not be attributed exclusively to the species, but rather to the soil characteristics prior to plantation, soil preparation practices and intensity of biomass removal (Madeira & Fabião, 2012). This is supported by the results of a 10-year-long pedogenesis experiment in which organic residues from eucalyptus were found to have much higher pH values and concentrations of non acidic cations than those observed for organic residues derived from other species, e.g. *Q. suber* and *P. pinaster (*Madeira & Ribeiro, 1995). Thus, evaluation of soil nutrient status must be considered in the context of the management practices applied and the specific ecological conditions of the site.

Management of organic residues (harvest residues and organic layers) may affect chemical soil characteristics, especially soil nutrient status. A field experiment revealed that the lowest pH was reached in areas where organic residues were removed (Magalhães, 2000). The concentration of exchangeable non acidic cations (and of extractable Al) and of extractable P in *Cambisols* (high nutrient status) were more favourable in the case of residue incorporation. However, removal of organic residues did not lead to significant changes in such characteristics, as the respective values were similar to those observed in soils in which the residues were maintained on the soil surface. In contrast, in the case of a *Lixisol* (low nutrient status), a significant decrease in non acidic cations and extractable P occurred as a result of organic residue removal. These results suggest that soil degradation risks associated with organic residue management (biomass removal intensity) may be dependent on soil characteristics and, therefore, on site specificity. Although evaluation of different organic residue management options did not reveal any significant differences in the potential N mineralization (Madeira & Fabião, 2012), N leaching may be strongly reduced through incorporation of harvest residues into the soil or by the herbaceous vegetation (Gómez *et al.,* 2008) during the early stage of establishment of replanted eucalyptus plantations. Such findings suggest that the management of organic residues is of utmost importance for N retention in the soil in the early phase of plantations, when absorption by trees is still limited.

Soil organic matter status

The soil organic matter concentration in former eucalyptus plantations did not vary consistently, as it was either higher or lower than that observed in reference (relatively undisturbed) forest systems (Madeira & Fabião, 2012). However, the soil organic matter in eucalyptus plantations showed differences regarding the C/N ratio and the characteristics of the humic fraction: lower N content and a more accentuated aliphatic character than in the reference forest (Madeira, 1986).

Nevertheless, the soil organic matter content in eucalyptus plantations may also be strongly dependent on initial soil conditions and on the intensity of soil perturbation (Figure 1) associated with practices used for site preparation, as the extent of the decrease is correlated with the intensity of perturbation (Madeira *et al.,* 1989). In addition to nutrient losses, conventional soil preparation for installation of forest plantations may, as already mentioned, lead to important changes in soil quality associated with a decrease in organic C content (Madeira *et al.,* 1989), as the rotation period is insufficient for recovery of initial values (Madeira *et al.,* 2002a).

As observed in the aforementioned pedogenesis experiment (Madeira & Ribeiro, 1995), eucalyptus residues are not different from those of other forest species regarding accumulation of organic matter in the soil. This study also revealed that the amount of organic C accumulated in the soil was very low relative to the amount of residues applied (equivalent to litterfall of a 45-yr period), suggesting that accumulation of organic matter derived from aboveground residues occurs slowly in the soil. However, other studies showed that the proportion of C associated with decomposing fine roots retained in the soil may be greater than the amount associated with the litterfall that is maintained or incorporated in the soil (Madeira *et al.,* 2002b), suggesting a crucial role for belowground biomass in the accumulation of organic C in soils in eucalyptus plantations.

Different methods of managing organic residues (harvest residues and organic layers) did not significantly affect the amount of organic C in the system. At the end of the first rotation, the amount of organic C in the organic and mineral soil layers was similar in the different treatments, indicating that the resilience of the system was sufficient to minimize the effect of residue removal. This suggests that most of the existing carbon in organic residues was returned to the atmosphere, confirming previous results obtained in a lysimetric experiment (Gómez-Rey *et al.,* 2008), in which removal or addition of huge amounts of organic residues did not lead to significant variations in the organic C concentration in the soil. Therefore, harvest residues can be used for bioenergy purposes if the site is sufficiently resilient to the effects of nutrient removal; however, this must be confirmed in long-term studies.

Soil physical conditions

The bulk density of the surface horizons of most forested soils is rather low. Nevertheless, increased bulk density following soil compaction is usually a problem in soils of forest plantations when heavy machinery is used, especially during the rainy season. Increased compaction usually indicates a poor environment for root growth and undiserable changes in hydrological function, such as reduced hydraulic conductivity and water infiltration rate (B.C. Ministry of Forests, 1999).

Several studies have revealed that soil physical conditions (bulk density, infiltration rate, hydraulic conductivity) in former eucalyptus plantations were less favourable than those observed in relatively undisturbed forest systems (Madeira & Fabião, 2012). This pattern may be associated with initial soil conditions and soil perturbations associated with site preparation. Indeed, the results of a field trial showed that the conventional intensive soil preparations involved in establishing new eucalyptus plantations greatly increased compaction of topsoil at the beginning of the rotation, thus increasing bulk density and decreasing aeration porosity, hydraulic conductivity and infiltration rate (Madeira *et al.,* 1989). Although total recovery did not occur during the rotation period, this did not affect plantation growth (Madeira *et al.,* 2002a).

The implications of management of organic residues (harvest residues and organic layers) (removal, maintenance on surface and incorporation into the soil) on the productivity of eucalyptus plantations and on soil physical conditions were also evaluated in two field experiments in replanted areas (in a flat landscape), under different ecological conditions (regarding climate and soil); all operations were conducted under optimal soil moisture for machinery operations (Jones *et al.,* 1999). Tree growth and tree nutrition status were not significantly affected by different management systems (Magalhães, 2000). In addition, soil physical characteristics (e.g. bulk density, compaction, aggregation stability index and aggregate mean weight diameter) were not significantly affected, to a depth of 10 cm, by different management harvest residue options in either *Cambisols* or *Lixisols* of a sandy loam texture (Magalhães, 2000).

This indicates that removal of residues or harrowing (to incorporate residues) did not induce significant changes in soil physical conditions. However, low water infiltration rates were more frequent in areas in which organic residues were removed, suggesting that the removal negatively affected the porosity of the topsoil layers and surface soil characteristics, thus creating conditions that favour surface run-off. Operations involving the use of heavy machinery in wet soil conditions and in rugged landscapes may cause important changes to soil physical conditions.

Soil erosion

The aforementioned effects of harvest residue management on soil quality in eucalyptus plantations represent short-term trends within a period of one rotation. However, it is not known if the trends will continue during a second or third rotation. Thus, long-term studies are essential to clarify the effects of residue management on soil quality. Such studies should also take into account the influence of the removal of stumps and structural roots (and associated perturbations), which is widely implemented nowadays.

Experiments regarding soil preparation and harvest residue management were applied at plot scale in sites with similar soil type and flat to gently undulating landscape, thus creating conditions highlighting the specific effect of management systems. The trials were managed under good forest practice, especially with respect to soil moisture conditions for heavy machinery operations. Therefore, the results obtained do not take into account some key factors associated with the current management of intensively exploited eucalyptus plantations (e.g. perturbations associated with installation and harvesting of forest plantations). A high proportion of these plantations are installed in heterogeneous areas in relation to soil type, in undulating, strongly undulating or even rugged landscape.

Soil perturbations associated with commonly used methods of tree removal, namely the use of heavy machinery (e.g. skidders and forwarders), under inadequate soil moisture conditions, favour negative changes in soil physical conditions, thus enhancing soil compaction. In addition to disruption of the forest floor and compaction of soil in the harvested area, wheeled vehicles transporting logs may cause wheel ruts (easily formed in wet soils), which channel run-off and initiate gully erosion. Landing decks where logs are piled and loaded onto trucks may also disturb soil and compact the topsoil. In this context it is important to schedule plantation harvesting (avoiding periods when soil is wet) by taking into account soil susceptibility to compaction.

Activities associated with replanting or establishment of new plantations (e.g. harrowing, ripping) cause strong soil perturbations due to the use of heavy machinery. This is sometimes associated with removal of stumps from former plantations and may lead to substantial losses of nutrients and soil organic carbon; such soil perturbations enhance negative effects on soil physical conditions associated with soil compaction. Therefore, soil perturbations should be minimized, and entry of machinery in plantations should be scheduled to periods with appropriate soil moisture conditions.

In eucalyptus plantations located in strongly sloping terrain, soil loss by sheet erosion, rill erosion and gully erosion, and even landslides, may occur, especially during the inter-rotation period when the soil is unprotected (Figure 2). Such patterns can be prevented by limiting residue removal or maintaining natural vegetation strips, both of which are associated with soil conservation practices such as contour ripping and terrace construction (Figure 3). Forest fires also represent a risk regarding soil erosion, especially in rugged areas.

Forest roads (and to a certain extent firebreaks) that provide access to the area by trucks and machinery for harvesting operations may also be a major cause of accelerated erosion in forested watersheds and therefore of soil degradation at the management unit scale (Figure 2). Appropriate design and management of roads and fire breaks is essential to minimize soil loss in eucalyptus plantations.

Inadequate design of forest roads may lead to soil loss by erosion of the road surface, the drainage ditch walls, or the soil exposed by roads cut into the hillside; roads associated with terrace construction, in areas comprising sedimentary materials, may also favour landslides. Collection and channelling of huge volumes of water in forest roads may cause formation of gullies. Roads should be managed to avoid these risks, by

Figure 2. Forest area (before replanting) effected by sheet and rill erosion (left) and road forest in a replanting area showing sediment transport and deposition, and gully formation (right).

use of the following measures: laying of adequate road surface, lining ditches with rocks, and establishment of vegetation on exposed road cuts or provision of cross channels (shallow ditches) to prevent water accumulating and to allow it to spread safely to areas protected by vegetation. Obviously, use of forest roads by vehicular traffic should be avoided during rainy periods.

Buffer vegetation strips should generally be left untouched along streams in planting and replanting areas to avoid erosion. Strips of dense vegetation may also be effective in removing sediment and nutrients from run-off, thus protecting the stream from logging debris.

Several studies indicate the need to implement management practices to prevent soil degradation, thus ensuring soil quality in intensively managed eucalyptus plantations. In this context, the risks and threats of soil degradation at the plantation management unit should be considered along with landscape planning within the context of land units. In other words, soil protection should be taken into account in the strategies and management practices applied to the plantation landscape at different scales. Thus, the intensity of management systems aimed at producing sustainable intensive forest plantations should be compatible with site ecological capacity, safety of soil and water (and other environmental considerations) and, obviously, with economic and social benefits. In short, management practices should be appropriate to specific types of soil.

Figure 3 - Areas replanted with eucalyptus after implementation of practices to control erosion: terraces with strips of natural vegetation (left) and contour plantation following contour soil ripping (right).

In this context, forest planning and management should include evaluation of the nature and intensity of soil degradation risks to enable implementation of appropriate management practices. Assessment of compaction and erosion is particularly important. The management practices used to establish (or re-establish) plantations and the respective exploitation operations must be considered in order to avoid degradation of soil physical, chemical and biological characteristics and modification of soil functional processes that may affect the sustainability of intensive forest systems. The effects on soil quality of the different practices used to establish and exploit eucalyptus plantations should therefore be subjected to adequate monitoring systems at the management unit scale.

Conclusions

The effects of management systems on soil quality in intensively managed eucalyptus plantations are specific to site conditions, especially those associated with the relief and the characteristics of the soil and parent material. Whether or not eucalyptus plantations reduce soil quality depends on management practices, as with other tree species. Thus, intensive management may lead to soil degradation, although it may also maintain or even improve soil quality. Management systems should therefore be adapted to soil and site characteristics, according to the associated risks and threats of soil degradation. Long-term evaluation of the effects of intensive forest management systems on soil quality should include systems for monitoring degradation processes, especially soil and carbon losses, at the management unit scale.

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References

B. C. Ministry of Forests. 1999. Hazard assessment keys for evaluating site sensitivity to soil degrading processes guidebook. 2nd ed., Version 2.1. *For. Prac. Br.,* B.C. Min. For., Victoria, B.C. Forest Practices Code of British Columbia Guidebook.

Brady N. C. & Weil R. R. 2008. The Nature and Properties of Soils. 14th Edition revised. Pearson International Edition, Pearson Education, Inc., Upper Saddle River, New Jersey.

Costa A., Madeira M. & Lima Santos J. 2014. Is cork oak (*Quercus suber* L.) woodland loss driven by eucalypts plantation? A case-study in southwestern Portugal. iForest 7:193-203.

Gómez-Rey M.X., Madeira M. & Vasconcelos E. 2008. Effects of harvest residue management and legume cover on growth of pine seedlings, nutrient leaching and soil properties. Annals of Forest Science. Available from www.afs-journal.org; DOI: 10.1051/forest:2008063.

Jones H.E., Madeira M., Herraez L., Dighton J., Fabião A., Gonzalez-Rio F., Fernandez-Marcos M., Gómez C., Tomé M., Feith H., Magalhães M.C. & Howson G. 1999. The effect of organic-matter management on the productivity of *Eucalyptus globulus* stands in Spain and Portugal: tree growth and harvest residue decomposition in relation to site and treatment. Forest Ecology and Management 122(1-2): 73-86.

Madeira M. 1986. Influência dos Povoamentos de Eucalipto (*E. globulus Labill.*) no Solo, Comparativamente aos Povoamentos de sobreiro (*Q. suber L.*) e de Pinheiro (*P. pinaster Ait.*). Tese de doutoramento. Instituto Superior de Agronomia, UTL, Lisboa.

Madeira M. 1989. Changes in soil properties under *Eucalyptus* plantations in Portugal. In: J.S. Pereira & J.J. Landsberg (editors) Biomass Production by Fast-Growing Trees. Dordrecht: Kluver Academic Publishers, pp.81-99. (ISBN: 0-7923-0208-7)

Madeira M., Azevedo A., Soares P., Tomé M. & Araújo M.C. 2002a. Efeitos da lavoura profunda e da gradagem nas características do solo e na produtividade de plantações de Eucalyptus globulus. Revista de Ciências Agrárias 25 (1,2): 158-169

Madeira M. & Fabião A. 2012. Implicações da remoção da biomassa florestal residual nas características do solo e na sustentabilidade da produção. Relatório efectuado no âmbito do protocolo entre a Altri Florestal, o ISA e a ADISA com vista à avaliação técnico-científica de impactes de sistemas de gestão e exploração florestal. ADISA, ISA/CEF, Lisboa.

Madeira M., Fabião A. & Carneiro M. 2012. Do harrowing and fertilisation at middle rotation improve tree growth and site quality in *Eucalyptus globulus* Labill. plantations in Mediterranean conditions? European Journal of Forest Research 131(3): 583-596.

Madeira M., Fabião A., Pereira J.S., Araújo M.C. & Ribeiro C. 2002b. Changes in carbon stocks in E*ucalyptus globulus* Labill. plantations induced by different water and nutrient availability. Forest Ecology and Management 171(1-2): 75-85.

Madeira M., Melo G., Alexandre C. & Steen E. 1989. Effects of deep ploughing and superficial disc harrowing on physical and chemical soil properties and biomass in a new plantation of *Eucalyptus globulus.* Soil Tillage Research 14(2): 163-175.

Madeira M. & Ribeiro C. 1995. Influence of leaf litter type on the chemical evolution of a soil parent material (sandstone). Biogeochemistry 29(1): 43-58.

Magalhães M.C. 2000. Efeito de técnicas de preparação do solo e gestão dos resíduos orgânicos em características físico-químicas do solo de plantações florestais. Dissertação de Doutoramento. Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Lisboa.

Implementing forest management practices for soil protection

Synergy and partnerships between forest owners and water operators

Bernard Bechevet

Abstract

Intensive discussions have taken place between the CRPF (Centre Régional de la Propriété Forestière, Regional Centre for Forest Ownership) and forest owners both during and after the INTERREG Alpeau project carried out at the Mount Forchat site. Small forest owners expressed interest and a group was finally formed. This led to the creation of a French association known as the «Association Syndicale Libre Forestière du Mont Forchat». The Association aims to enable profitable trading of timber and to manage the forest in order to prevent degradation of the soil and springs and also to encourage natural regeneration of spruce and broadleaved species. A partnership has been established with SIEM (Syndicat Intercommunal des Eaux des Moises, a public water operator serving 40000 people) to prevent degradation of the springs. Selection cutting is now implemented for a tree volume of more than 3000 m^3 to be cut during 5 years. A surface area 100 ha (hectares) is currently managed between 42 members. The aim is to increase the number of members and the surface area (to a total forested area of 500 ha) and also to design new plantations when clear cutting is carried out. There is some concern about spread of the bark beetle, and we hope that these concerns will be addressed in future European projects.

Geographical location

Mount Forchat is located near the Swiss town of Geneva (40 km) and the French towns of Annemasse and Thonon. It is also close to the towns of Evian (30 km) and Chamonix (Mt Blanc) (60 km). The summit of Mt Forchat is 1539 m and the base is 750m ASL. Mount Forchat covers an area of 500 hectares within which 5 springs are exploited. The location of the forest is shown in Figure 1.

The region has undergone significant development in the last 50 years due to the proximity of Geneva and the large increase in the local population: e.g. the population of the small town of Habere-Poche (at the base of Mt Forchat) has increased in the last 20 years from 440 inhabitants to the current level of more than 1200. This major change in population has lead to an increased demand for infrastructures (e.g. roads and schools) and

Figure 1. Mt Forchat forest area.

water supply. Water consumption in this area, which includes the SIEM (Syndicat Intercommunal des Eaux des Moises) and the Habère-Poche and Lullin communes (note, a commune is a French administrative division) is ~2.1 million cubic metres. Water is supplied by the springs around Mt Forchat and by a water purification plant that obtains water from Lake Leman. The total amount of water supplied by the springs is ~1.6 million cubic metres. The forest cover mainly comprises spruces and broadleaved trees (beech). Tourism is also important and includes both winter tourism, in the small ski resort of Habère-Poche, and summer tourism. The population increases to twice the normal size during these holiday periods (and the stress on water is also at least twice as high). Two systems exist for the control of water production: one is the SIEM and the other involves management by the communes themselves. The SIEM, which includes 15 communes, is the largest water consumer because the area involved is much larger than the forest domain of Mt Forchat. The technical management of SIEM is one of the most efficient in France and is often used as an example. In the early 17th century, the forest mainly comprised broadleaved tree species (beech) and monks undertook deforestation of the area to provide the inhabitants with more agricultural land.

History and evolution of the Mt Forchat forest area

We will consider the situation of this area in 1934 (i.e. 80 years ago) to help us understand how the forest has developed. At that time, the Habère-Poche commune was occupied by farmers (80 %) and craftsmen (joiners, carpenters, stonemasons) (20 %). During winter, the farmers worked in the forest to produce timber for firewood and also for carpentry work. There was a balance between the timber demand and forest growth because the exploitation did not exceed the manpower level. No mechanization was used - only horses and manual labour. The 40 farmers in the Habere-Poche commune needed meadows to provide food for cows and goats. Fodder (e.g. hay) was required for the long winter in the mountainous climate. During this period, no other food was available (e.g. flour was not available for animals), so that pasture covered large areas and the forest was maintained at the top of the mountain where it is very difficult to harvest grass to produce hay. The past and present levels of the forest can be seen in the photographs shown below (Fig. 2).

This change in landscape is due to the rural migration that began in the 1960s. The need for manpower in the new industrial plants established after the Second World War and the poor revenue from agricultural exploitation led to this abrupt change. The inhabitants moved to large towns where higher incomes were available. The land was then abandoned because the mechanization required to farm the land and make a living was not compatible with the steeply sloping terrain. The consequences of the land abandonment include the following:

- Some farmers planted spruces without technical know-how (they planted them in the same way they planted leeks) and obtained subsidies to buy young seedlings (3 to 5 years). They subsequently abandoned the plantations, which they had originally thought that the next generation would continue to manage.

- Farmers abandoned the area leaving wild forest to invade the land.

- Climate change has also enabled the forest to become established in higher areas of the mountain. The forest has spread very rapidly in the last 80 years, and most of the area is now occupied by spruce.

The price of timber has also changed enormously. Eighty years ago forest owners could sell forest land for high profit. Natural regeneration of the forest enabled sustainable forest production for the next generation. The situation today is completely different and it is no longer clear whether the forest is profitable.

The current status of the forest can be summarised as follows:

a) The forested area has increased greatly and the trees are now old enough to be exploited.

b) Considering the effects of land inheritance and design of former agricultural plots, the surface area of forest plots currently ranges between 0.18 ha and 13.5 ha.

c) It is impossible for small forest owners to make profits by exploiting the plots.

d) The storms of 1999 and 2002 caused a great deal of damage to the forest. The price of wood fell and excess supplies of wood lasted for about 10 years.

e) Several private wood exploitation operators combine small areas for clear cutting to earn money while disregarding soil degradation or the need to re-establish plantations. Management driven by short-term benefit leads to serious damage to the forest ecosystem.

f) The springs sometimes become polluted and the water temporarily undrinkable.

In light of the above, the question arises as to whether the forest is still profitable and, if so, to what extent.

A rough calculation gives the following results:

- Considering a surface area of 10000 m^2 (1 hectare) in the Mt Forchat region:

—cost of buying the land: ~2000€

—cost of plantation: ~2500€

—cost of maintenance during the first 10 years: ~2000€

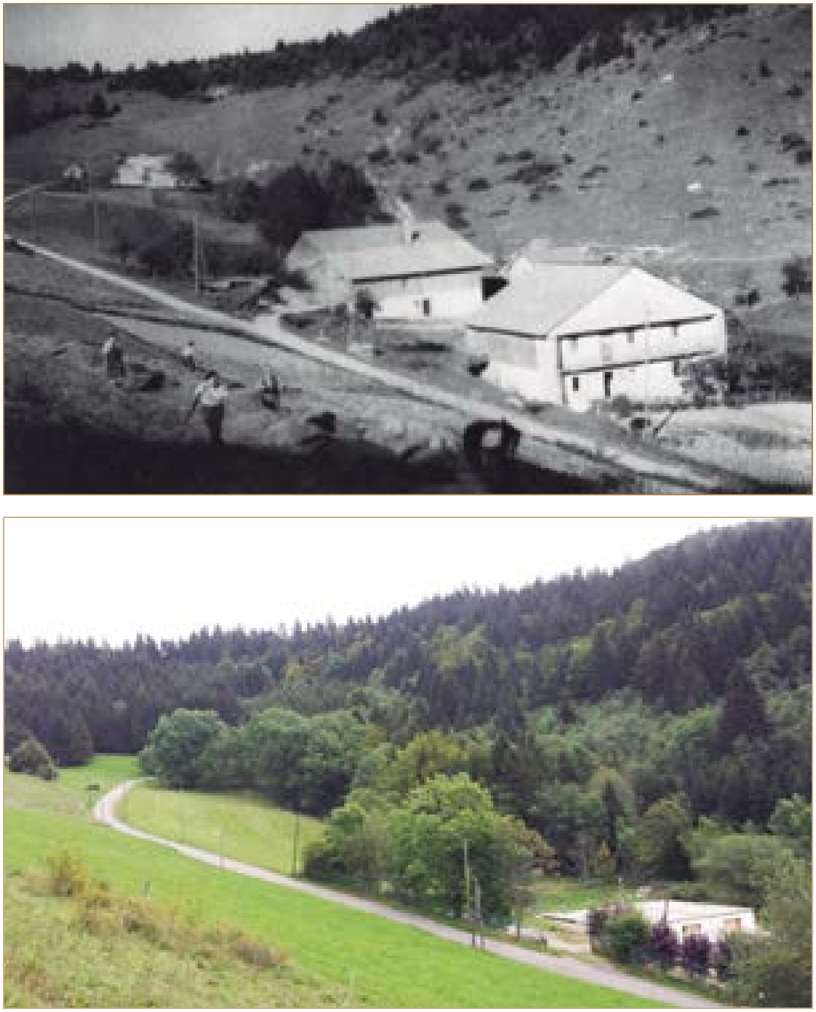
—taxes per year: 20€ .

- Thus, also considering that the forest will be exploitable after 75 years and that the current price of standing wood is ~ 45€/m^3

—outlay for expenses: 8 000 €

—expected revenue: 20 250 € (450 m3/ha).

Net revenue: 12 250 €, which represents 163 €/year.



a) 1934.

b) 2014.

Figure 2: The same site a) in 1934 and b) at present (2014)

This is a favourable case in which storm-damage or degradation of the forest is not considered. However, the following risks should also be added:

- Degradation of young plantations (by roe and other types of deer): between 10 and 50 %.

- Storms: the future frequency of which is no known. According to the latest climate change predictions, large storms (such as the 1999 storm) will occur every 30 years. Half of the forest (or even more) may be destroyed by such storms.

The revenue may thus decrease by more than half (or even be reduced to zero). The profitability of the forest can thus be estimated to be between 0 (even negative in case of destruction by a storm) and ~2 % (taxes excluded), with a return of the investment in 75 years.

The INTERREG project “Alpeau” showed that forest and water are closely linked. Although this is obvious, it is not very well understood. Water purification mainly occurs in the first 20 cm of the ground (Fig. 3). In the absence of tree (or other vegetation) roots, the rainwater enters the springs directly, with potentially negative effects on drinking water quality. This is an extremely difficult situation for water operators. During the storm of 1999, spruces were uprooted and areas of bare ground appeared. Moreover, extraction of wood in unsuitable conditions also affected soils, with increased pollution risks for the underground springs.

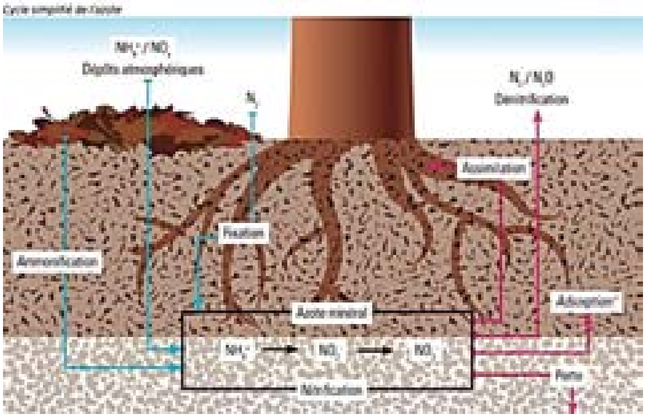


Figure 3: Purification of water in the forest (courtesy of SIEM). (Simplified diagram of the Nitrogen cycle: NH_4+/NO_x Atmospheric inputs; N_2/N_2O Denitrification; Assimilation Ammonification; Fixation; Mineral nitrogen; Adsorption; Nitrification; Loss: this is the classical water purification cycle).

The prices of spring water and purified water are very different. The respective costs of producing water are estimated to be ~1 ct€ per m^3 for forest spring water, ~ 4 ct€ / m^3 for bored spring water and ~ 20 ct€ / m^3 for plant-based purification from a lake. Water operators (and local inhabitants) are obviously very interested in protecting springs from pollution. If the level of consumption of spring water is 1.6 million m^3 (for the area considered and for one year) the benefit associated with obtaining clean forest spring water is 1.6 X 0.19 = 0.304 M€ (304 000 €) for a turnover of ~ 500 000€ (only for water cost of ownership). Protecting the forest is in the interest of all, as concluded by some forest owners and water operators 3 years ago. The synergy between these two groups is profitable and a partnership is highly desirable.

Objectives of the association and partnership

Following recent considerations on climate change and landscape evolution, concern about water supplies and the profitability of forests, several forest owners have combined forces in an attempt to make the Mt Forchat forest minimally profitable and also take into account the springs in the area. The main objective of the association is to manage the forest sustainably and profitably in partnership with water operators.

The potential benefits are as follows:

- Protection of the forest from storms by mixing different trees species (spruce and broadleaved species, mainly beech) to increase resistance and resilience to wind damage.

- Construction of a partnership with water operators to exploit the forest while protecting the springs.

- Exploitation of the forest to favour natural regeneration (which decreases the cost of plantation and maintenance, which is 60% of the cost of forest management, but lowers the profitability).

- Scheduling of the selection cutting to target the sustainable forest for the next 75 years.

- Elaboration of exploitation specifications that respect nature and the springs.

- Negotiation of subsidies with water operators to fill the gap of the extra costs induced by the exploitation specifications.

The photograph in Figure 4 illustrates what we would typically like to prevent in the future. Clear cutting is not permitted in forest stands of surface area more than 5000 m^2 that are located near drinking water catchments.

However, this is often overlooked by wood operators who, in order to maximize profits, do not always respect the law. Soil degradation may have serious consequences for water quality and also for the forest itself as neighbouring forests are generally strongly affected by clear cutting and because bark beetle develops preferentially in degraded areas (we have noted this type of degradation close to areas where clear cutting has been carried out).

Current actions

After defining the objectives of the association, a number of meetings have been organised with the help of the CRPF (Centre Régional de la Propriété Forestière – Regional Centre of Forest Ownership) and also the SIEM. It was decided to create the Association and to complete all the administrative requirements. In May 2012, the Association was declared official (in the « Journal Officiel ») and was duly registered. At the outset, the number of members was 30 for a surface area of 60 ha. A committee was elected with a president, a secretary and a treasurer. SIEM is a member (and secretary) of the Association as it owns forest.

The first work of this team was to draft the official « PSG » (Plan Simple de Gestion - Forest management plan), and subsidies were awarded by the Rhone-Alpes Region (the documents were made by COFORÊT and agreed by the CRPF). The total cost of the plan was 10000€, which was paid by the SIEM, the Rhone Alpes region and the Haute Savoie department. The PSG was available free for the first members. The PSG includes plans for maintenance of the forest during the next 10 years that take into account the present state of the forest.

The first decision made was that a volume of 3000 m^3 of the forest should be cut (over 60 hectares). This was not initially possible for the Association, and the task was therefore spread over 5 years (600 m^3/year).

Exploitation specifications were then elaborated. These specifications were estimated to induce an extra cost of approximately 6 €/m^3 (i.e. ~ 26€ instead of 20€). The main specifications outlined in this document are as follows:

- Use of selective cutting of trees (favouring a mixture of species).
- Use of woodcutters and extraction companies sympathetic to the Association's aims (these companies will eventually be certified by the association).
- Use of biodegradable oil in machinery.
- Exploitation only in dry weather when the ground is clear (lanes and tracks must be given at the end clean, with no soil degradation).

Figure 4: Clear cut area showing forest degradation and bark beetle development.

- Planting when necessary with mixed spruce/broadleaved species (beech).
- Control of natural tree regeneration.
- Control of development of bark beetle.

A 5-year-long partnership has been signed between the Association and SIEM, which enables forest owners to obtain a grant of 6€/ m^3 to exploit the forest while respecting the specifications (a French law enables this subsidy to favour water protection and adsorption of CO_2).

In 2014, the first two timber yards were organised for a volume of 700 m^3. The very bad weather in the summer has delayed work, which is still in progress. The exploitation is designed to favour selective cutting. It is difficult to carry out selective cutting in a forest in which the trees are of similar age. Therefore, COFORET technicians selected which trees (spruces) to cut to enable natural regeneration. The difficulty involved in cutting down two trees and leaving one undamaged tree between them is illustrated in Fig. 5.

Figure 5: Selection cutting. This is very precise work.

The association reports that bark beetle has developed very rapidly this year and one timber yard has been affected. A decision therefore made was to cut all the trees close to the trees affected by the bark beetle.

At the same time, the Association, in partnership with SIEM, has helped in the construction of a forest track, which will enable forest owners to harvest the forest, which means facilitating the exploitation by facilitating access to the forest by trucks. The cost of constructing this track (for use by trucks and timber harvesting machinery only) (120000€) was financed by grants from the European Union, France, the Rhône-Alpes region and from SIEM. Construction of the track was possible because of the agreement reached with forest owners.

During the last two years, several new members have joined the ASLF. The number of members has risen to 42 and the surface area of forest managed has increased to 100 hectares. The Lullin commune (which owns public forest, part of which is not managed by ONF) has joined the ASLF to enable management of the communal forest not managed by ONF (Office National des Forêts – National Forest Office) (and the Habere-Poche commune will probably do the same). The Habere-Poche commune is the latest member to join the ASL (after September 2014).

Discussion is in progress with the UFP74 (Union des Forestiers Privés de Haute-Savoie – Haute-Savoie private forest owners union) to enable the members of ASLF to become part of UFP and thus be eligible for insurance. The ASLF is also negotiating the PEFC certification (in case of exploitation by COFORET, the PEFC label has already been established).

Prospects

Several objectives have been identified for the next few years:

- Organization of the next cutting operations, following the PSG (using cable harvesting if possible).
- Upgrading the PSG and finding the budget to implement the plan (surface area of 40 hectares).
- Organization of planting (for this year, 3 hectares must be planted and the budget is under discussion). The main problem for the forest owners is financing the operation (note that the forest was generally exploited several years ago or was not exploited because of the storm).
- Extension to new members. The example of the two timber yards should capture the interest of neighbouring forest owners who are not yet members. A new meeting will be organised with personal invitations to these forest owners (mailing done by SIEM and CRPF). The target is to increase the surface area to 300 ha (this is a first step, it will probably be impossible to involve all of the owners) and the number of members to 100 (the total number of forest owners is 600 for 500 ha; the total surface area of private forest is 350 ha).
- Try to motivate the Habère-Poche and Lullin water operators to participate in the ASL budget.
- Draw up a contract for the partnership with CRPF, for a minimum of 5 years.
- Coordinate the actions with ONF.
- Find European projects to study the Association’s model, highlighting the mutually beneficial partnership between water operators and forest owners.
- Warn about the development of the bark beetle and attempt to find a solution. Further spread of bark beetle could be catastrophic for the forest and the water supplies. Investigation of ways of halting this disease is urgently needed.

Conclusion

The ASLF arose from the synergy between the water operators and the forest owners and as a result of the INTERREG Alpeau project. This partnership enables forest owners to be financed by water operators, to ensure sustainable forest management and protection of springs. Water and forests are fundamental for life. Forest profitability is impacted by the occurrence of natural disasters and by competition with raw materials produced in countries with lower labour costs or with timber produced in intensive production regions and competing with small surface stands is difficult with the subsequent risk of degradation of our forests. This risk is enhanced by the predicted climate change scenarios (higher temperature and number of storms). Studying a new type of forest management that includes selective cutting and natural regeneration with exploitation specifications can reduce this risk. However, this type of sustainable management is incompatible with current timber prices, and forest owners must therefore be financially supported (specifically small forest owners). The top candidates for granting financial help are the water operators who are the first to be affected by poor management of the forest. The subsidies granted from SIEM to ASLF represent only ~ 0.5 % of SIEIM's turnover, and a minimum of 1.5 % is necessary. However, if the price of wood stays at the current level it is unlikely that interest will be shown in the forest (the profit from investment is too low). To be profitable, the price should increase by 50% (i.e. to 80 €/ m3). A « Forest water » label should ideally be created.

Protection of forest and control of motor vehicles must be effective. Forests are very fragile and we cannot afford to pollute then by unnecessary activities, even though tourism will be affected.

ASLF is fighting for all these objectives, which are not exceptional, but simply aimed at protecting life.

Acknowledgements

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Mount Forchat – Haute Savoie – France.

Woodlands for drinking water: best management practices and partnerships

Julien Fiquepron, Olivier Picard, Aurelien Bansept and Eric Toppan

Abstract

Forest managers can help provide an efficient way of producing cheap, high quality drinking water. Foresters can be proud of their role in preserving clean drinking water resources, and this role deserves to be given greater prominence. This study examines how forest managers can be involved in producing good quality water for drinking purposes through innovative contracting methods rather than compulsory utility easement or expropriation. Private forest organizations in France are developing this solution, with financial support from *France Bois Forêt* (the French interprofessional association of wood and forest sectors) and in close collaboration with local water supply services.

Workshops have been organized in order to draft contracts defining the agreements that can be reached between forest owners and water supply operators, and model contracts have been proposed. Depending on the service considered, additional objectives can be defined in the contract: afforestation - dedicated forestry practices (ranging from felling operation methods to forest stand management) - coordinated management of forest stands - "forestry water" certification (for drinking water produced in forests where owners are committed to implementing practices that preserve and ensure good water quality).

The project pilot phase has been implemented in the Mont Forchat site (Haute-Savoie, Alps, France), with a local water supply service - the SIEM (Syndicat Intercommunal des Eaux des Moises). The SIEM takes particular care to protect its resources, especially woodland springs in mountain areas. Under a Franco-Swiss Interreg project (Alpeau), comparison of the operating costs for different water catchments managed by the SIEM (woodland springs, boreholes, pumping from Lake Geneva) showed that pumping lake water was 29 times more expensive than tapping water from woodland springs. It is therefore vital to preserve these resources, which can be used to supply natural water at very competitive prices. Thus, the SIEM has created an association with forest owners, in order to identify mutual interests regarding forest areas above the springs. This is an innovative contracting method, applied in addition to existing regulations.

Forest managers have also carried out technical projects aimed at optimizing forest practices for protecting water. Woodlands help to protect water resources, but they must be cared for to make their protective role as

effective and enduring as possible. One main result of the projects is the publication of technical guidelines for good forest management practices to protect drinking water resources.

Land use management is a part of the process of producing drinking water, and the involvement of foresters can lead to the supply of high quality drinking water without the need for purification treatments. Forestry organizations in France are also applying this solution in other sites, with local water supply services and water bottling companies. However, political support and improved communication between the forest and water sectors are required before the model can be applied on a large scale. Financial resources, or more specifically different ways of using these resources, are also required as it is usually more cost-effective to fund prevention than remediation.

Introduction

Foresters are not only wood producers, but also land managers. They play a role in providing different goods and services, including water related services. Private forest organizations in France focus on issues related to drinking water and bottled water. This choice is motivated by three factors:

- Water quality issues persist and drinking water treatments are expensive.

- Catchments in forests are sought after because of the availability of good water quality at a competitive price.

- Some regulatory easements are restrictive for woodland management.

Forest managers can help provide an efficient way to produce cheap, high quality drinking water. Foresters can be proud of their role in preserving clean drinking water resources. This involves extensive management to maintain plant cover, soil protection and a low nitrate content in the groundwater, as well as to conserve the purifying functions of forests and the natural image of water in forest areas. This role deserves to be given greater prominence. The question is how to construct a fair partnership between forestry and water suppliers to maintain drinking water quality.

In the following section, we present some aspects of the links between forest and water, focusing on the qualitative aspect of water, followed by the regulatory procedure for protection of water catchments and a brief description of the « Eau + For » program, aimed at developing partnerships.

Forests protect water quality and foresters can help to maximize the protection

Forests have a positive impact overall on water quality, for two main reasons:

- The particular way that forest ecosystems function;
- forest management can limit the adverse effects of activities such as phytosanitary applications, fertilisation, soil stripping/sealing, *etc.*

This section focuses on some of the main issues related to forests and drinking water quality. Some reference documents provide more exhaustive information, such as that produced by the US Forest Service (Brown and Binkley, 1994).

Forests protect water quality

Woodland cover protects soils

Forestry is differentiated from other types of land use by a high level of aerial development, an extensive root network and the ability to generate porous soils that act as filters.

Soils under forest benefit from long-term protection, including prevention of high turbidity.

Forests mitigate run-off and soil erosion, by favouring interception and infiltration of precipitation.

In forests, plant layers and forest soils retain, slow down and filter water. In contrast, water quality is often at risk under cropped soils, because the soils remain bare at early stages of the crop cycle and after harvest.

Perennial cover mitigates leaching of mineral elements

Overall, the efficient functioning of biological cycles in forest stands optimizes the use of nutritional elements from the soil (Ranger *et al.,* 1995). This enables high biomass production, often from poor soils, and prevents loss of mineral elements from the soil/plant system. Recycling, especially of nitrogen, is important in forests. Nitrate levels are therefore low under forest cover (Gundersen, 2007). A measuring network in the Lorraine region showed that under forest cover, water in the rooting zone contained about 2 mg/l of nitrates (Benoît and Papy, 1997), whereas the nitrate content in agricultural soil was much higher (Table 1). Woodland is therefore the best type of land use for yielding low nitrate contents.

Land cover	$[NO_3^-]$ in water at a depth of 1.10 m (mg/l)
Forests	2
Cut fields	19
Pastures	31
Temporary grassland	28
Winter wheat	46
Rape seed	62
Spring cereals	120
Maize as a fodder crop	126

Table 1: Nitrate levels in water collected by porous-cup lysimeters at a depth of 1.10 m under different types of land cover in Lorraine (Benoît *et al.,* 1997).

How foresters can help to preserve water quality

The advantages of forest management

Management of forest land is less intensive than management of agricultural land, and interventions are less frequent due to the long-term rotations in forests. The use of agropharmaceutical products and fertilizers is very limited: herbicide treatments are 450 times less frequent in forests than in crops. Even with the most intensively managed types of forest, *e.g.* poplar or maritime pine, much less input (sometimes no input) is required than with classical crop production processes.

Healthy forest cover: also a priority for water protection

Although perhaps obvious, it is important to remember that healthy forest soil and forest cover are major assets for water quality. The priority is to have a healthy forest cover, as massive die-back may impact water quality, particularly in relation to nitrate levels (Gundersen, 1992). In a study of windthrow in Bavaria, maximal nitrate levels exceeded 100 mg/l in the seepage water in a 100 ha catchment area, with 80% mortality after an attack by bostrichid beetles (Attenberger *et al.,* 2002).

In a further step, foresters may attempt to favour resilience, i.e. the healing capacity of forest cover. Thus, mixed (different species) and uneven-aged stands are at less risk. Nevertheless, water quality may be well protected under even aged forests.

Bare soils: the main critical point

Perturbation of soil on slopes, close to shallow springs or surface water leads to risk of increased turbidity[1]. The major causes of soil perturbation in forest are logging operations, forest road construction and to a lesser extent, soil cultivation before plantation. The risks associated with logging operations include wood extraction and soil packing by vehicles. Although the risks are particularly high during the construction phase, a good forest road network is an asset for water protection. It enables safe circulation of vehicles and facilitates the fight against forest fires and mobilization of wood after windthrow or windbreak.

The use of phytosanitary products and the presence of hydrocarbons are also important aspects.

Forest guidelines for protecting water quality

With the aim of combining drinking water protection and wood production, private forest organizations in France published (in 2014) a guide entitled "Protect and value water from forest". The first part of the guide presents technical specifications, with practical forest guidelines, and the second part describes how to promote partnerships between foresters and drinking water operators. Below we include a summary of the main steps leading to specific recommendations (Figure 1). This work is mainly based on a guide produced by the CRPF of Midi-Pyrénées (Marty, Bertrand, 2011). For the sake of brevity, we include an example of the recommendations (end of Figure 1). The guide is available (in French) at the following link: http://www.foretpriveefrancaise.com/proteger-et-valoriser-l-eau-forestiere-445890.html.

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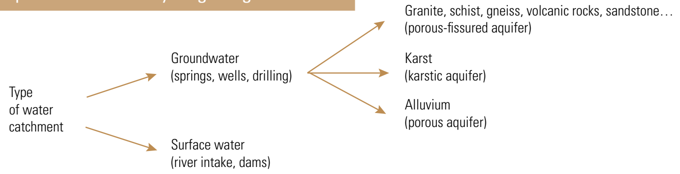
[1] Turbidity is characterized by cloudy water due to particles in suspension. Turbidity favours bacterial contamination.

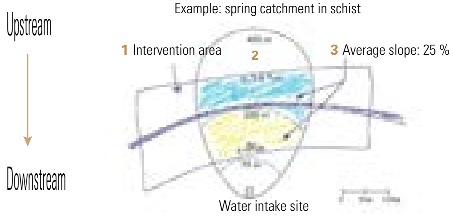
First step: determine the hydrogeological context



Each context refers to a specific field sheet and specific guidelines.

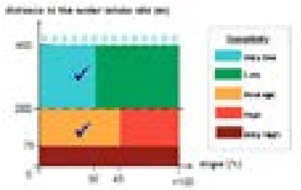
Second step: complete the field sheet

Example: spring catchment in schist



1 Establish the limits of the *intervention zone*, other useful elements (tracks, waterway…).
2 Measure *maximal and minimal distances* between the intervention zone and the water catchment.
3 Measure the *average slope* of the intervention zone.

Third step: place your site in the sensitivity diagram



Fourth step: use the table of guidelines

Here we consider another example: construction of a road within a distance of 75 m from the water intake site.

1	**Forest roads and tracks**				
2	**Turbidity**	Construction of forest roads or tracks			
		Sensitivity	Recommendations		
		Very high 3	Construction outside the sensitive zone 4	Compulsory 5	€ € € 6

1 **Type of operation**
2 Main pollution risk addressed by the recommendation
3 **Sensitivity**
4 Recommendation
5 Priority of the recommendation
6 **Additional costs of the recommendation**

Figure 1. Main steps leading to adapted guidelines.

The relevant recommendation is "Dealing with the turbidity risk. Construction of forest roads or tracks outside of the most sensitive zone (i.e. within 75 m of the water intake site) is compulsory, with additional costs of between a few hundred and several thousands of €/ha."

In summary, woodlands help to protect water resources, but they must be cared for to make their protective role as effective and enduring as possible. For vulnerable catchments, forest cover alone is not sufficient to guarantee a consistent supply of good water quality: foresters have a role to play.

Protection of drinking water catchments: constraints and contracts

We found a need to restore the balance of water policies in the woodland context.

At present, in France, protection of drinking water in forested catchments only relies upon regulatory procedures, without any accompanying measures. These procedures lead to expropriation in the public interest and compulsory utility easement (e.g. a ban on the construction of forest roads) that can affect forest management. Moreover, as many forestry companies and forest owners are not aware of the compulsory easements, compliance remains uncertain.

There is also a need for flexibility, as forest management may change. The regulatory procedure is designed to last for a long time - for as long as the water intake is used by the local community. It is difficult to foresee all forestry activities, and therefore difficult to give an accurate valuation of the constraints.

Finally, regulatory procedures are not by themselves a guarantee of protection. They require minimal monitoring and management to be efficient.

In light of this, we have identified two potential improvements:

The first, which concerns regulatory procedures, seeks to improve the dialogue and to award financial compensation for compulsory easement. Foresters are rarely consulted during the procedures.

The second improvement aims to develop complementary contractual solutions. Beyond the technical protection of water resources, this also represents a means of mobilizing foresters and acknowledging their role in water protection.

Developing partnerships, the « Eau + For » program

The « Eau + For » program has been developed by private forest organizations in France, in close collaboration with local water supply services - with financial support from *France Bois Forêt* (the French interprofessional association of wood and forest sectors).

This program aims to involve forest managers in the production of good water quality for drinking purposes, through innovative contracting methods rather than compulsory utility easement or expropriation.

Workshops have been organized in order to draft contracts defining the common interest of forest owners and water sector companies, and model contracts are available. Depending on the service considered, additional objectives can be established: afforestation - dedicated forestry practices (ranging from felling operation methods to forest stand management) - coordinated management of forest stands - “forestry water” certification (for drinking water produced in forests where owners are committed to practices that preserve and ensure good water quality).

We identified 20 priority sites. The pilot phase of the project has mainly been implemented at the Mont Forchat site (Haute-Savoie, Alps, France) in conjunction with a local water supply service, the SIEM (Syndicat Intercommunal des Eaux des Moises). The SIEM takes particular care to protect its resources, especially woodland springs in mountain areas. Under a Franco-Swiss Interreg project (Alpeau), comparison of the operating costs for different water catchments managed by the SIEM (woodland springs, boreholes, pumping from Lake Geneva) showed that pumping lake water was 29 times more expensive than tapping water from woodland springs. It is therefore vital to preserve these resources, which can be used to supply natural water at very competitive prices. The SIEM has created an association with forest owners, in order to identify mutual interest in forest areas above the springs. This is an innovative contracting method that can be used in addition to existing regulations (see the article by Bernard Bechevet in this special issue).

Conclusion

The involvement of foresters in protecting drinking water promotes the supply of high-quality drinking water with no need for purification treatments. Land use management must be recognised as a part of the process of producing drinking water. Private forest organizations in France are starting to apply this solution, together with local water suppliers and bottling water companies.

Woodlands play a protective role for water quality and foresters can reinforce drinking water protection. However, this protective role remains poorly known and acknowledged.

We identified two different means of progress: regulatory procedures and partnerships with water operators.

Private foresters in France have available operational technical and contractual tools to optimize drinking water protection. They want real partnerships with water operators, with fair compensation.

At present there are very few sites where such partnerships have been established, and so far only one contract has been approved. Obstacles exist on both sides (water operators and foresters). In the present study, we identified a strong need for local representation to encourage involvement of all interested parties.

References

Attenberger, E., K. Moritz, and H. Weber. 2002. Groundwater resources in Bavarian forest areas – Quality monitoring and protection approach. *La Houille Blanche* 3: 85–89.

Bansept A., Fiquepron J., 2014. Protéger et valoriser l'eau forestière, guide pratique national du projet « Eau + For », FPF CNPF, 156 p.

Benoît, M., and F. Papy. 1997. Pratiques agricoles sur le territoire et qualité de l'eau alimentant un captage. *In:* L'eau dans l'espace rural, INRA, 323-338.

Brown, T. C., and D. Binkley. 1994. Effect of management on water quality in North American forests. USDA Forest Service, 26 p.

Gundersen, P. 1992. Mass balance approaches for establishing critical loads for nitrogen in terrestrial ecosystems. *In:* Grennfelt, P., and E. Thörnelöf (Eds.) *Critical loads for nitrogen, a workshop report,* Nordic Council of Ministers, 55–110.

Gundersen, P. 2007. The impact of forest management on water quality. *In:* Raulund-Rasmussen, K., and K. Hansen (Eds.) Synthesis report on impact of forest management on environmental services, EFORWOOD report, 73-91.

Marty P., Bertrand P., 2011. Recommandations de gestions forestières pour les captages d'eau potable – guide pratique. CRPF Midi-Pyrénées, 87 p. http://www.crpf-midi-pyrenees.com/.

Ranger, J., M. Colin-Belgrand, and C. Nys. 1995. Le cycle biogéochimique des éléments majeurs dans les écosystèmes forestiers. Importance dans le fonctionnement des sols. *Etude et Gestion des Sols* 2 (2): 119-134.

The Scottish Soil Framework: Implementing soil protection policy at regional scale

Willie Towers, Helaina Black, Philippa Booth and Colin D Campbell

Introduction

In many countries, including Scotland, there is no explicit soil protection strategy. This in part reflects the multi-dimensional nature of soils which impacts on a large number of policy areas. These include agriculture, forestry, waste management, biodiversity, climate change, planning, renewable energy and water quality. Different properties and functions of soils are required in each of these policy areas; for example, soils that are highly productive for a wide range of crops may be of less value for biodiversity and if managed inappropriately, can have negative impacts on water quality. Another aspect is that while water and air are viewed as public goods; land (and soil) are often in private ownership and more complex governance has implications for regulation.

A fragmented approach to soils in policy has resulted but there has been an increasing recognition that some degree of co-ordination was required between different policy areas. An additional factor was the range of drivers and pressures that influences soil quality. These can range from global drivers like climate change to more local influences such as inappropriate use and management of certain soils and development pressures. The Scottish Government adopted a view that an over-arching framework was required to enable more dialogue between different sectors and ultimately a better cross-sectoral approach to soil policy, regulation and management.

Process leading to the publication of the Scottish Soil Framework

The development of the Framework followed a logical pathway. Firstly an evidence base was required both to describe and quantify the resource of the Nation's soil and its particular attributes, and to justify the need for a framework and to guide its development and priorities. In 2006, the then Macaulay Land Use Research Institute and Stirling University produced a report Scotland's Soil Resource – Current State and Threats (Towers *et al.* 2006). As the title suggests, Scotland's diverse soil resource was described and the range of threats to it were analysed. The threats included loss of soil organic matter, climate change, erosion, compaction, contamination, sealing, loss of biodiversity salinization and heritage value. A number of recommendations were made for each of these threats.

A scoring system was developed to determine what the main threats were to Scottish soils. This was qualitative but based on expert judgement and consensus. The criteria used were the consequence, spatial extent, uncertainty and reversibility of each threat. Threats from *erosion, compaction* and *contamination* (other than acidification) were judged to be of localised significance, although they can lead to loss of important functions. They were also assessed as being relatively straightforward to rectify. *Sealing, loss of biodiversity* and *acidification* were scored more highly as threats nationally, with sealing affecting almost all soil functions. *Climate change* and *loss of organic matter* were identified as the most significant threats to soil functioning, although uncertainty in the evidence here was also acknowledged.

In the summer of 2008, the draft Scottish Soils Framework (Scottish Government 2008) was published for consultation. It drew evidence from the previous report (Towers *et al.* 2006) and a number of the recommendations were developed further into proposals for action. Among its key points were:

- Acknowledged formally for the first time by Government the value of soils to Scotland.

- Set out the vision for soil protection in Scotland.

- It did not identify or propose new policies, rather it provides the framework for better co-ordination of existing ones.

- Included commitments to increased information availability, awareness raising and increased dialogue with stakeholders.

A key aspect was the concept of soil functions and the need to protect and enhance them for the benefit of society. Soil protection *per se* has less resonance politically and with the general public but if it were linked more closely to the 'services' that soils provide and the need to protect them, it was considered that soils would be seen in a more positive light. For the purist, this anthropocentric view of soils may be regrettable – soils are living entities after all – but the focus on soil functions does not diminish the value of soils in their own right. The soil functions are:

1. providing the basis for food, wood and biomass production

2. providing raw materials

3. providing a platform for buildings and roads

4. controlling and regulating environmental interactions: regulating water flow and quality

5. storing carbon and maintaining the balance of gases in the air

6. providing valued habitats and sustaining biodiversity

7. preserving cultural and archaeological heritage

These functions were not used merely as a scientific concept but indirectly as the basis of many of the Actions in the final Framework (see later).

At this point, two scientists from the James Hutton Institute were seconded to the Scottish Government, firstly to analyse the feedback from the consultation and secondly to provide technical advice to the Scottish Government in drafting the final Framework document. There was a clear distinction in roles: the policy team carried out the negotiations with different policy units in the Scottish Government to agree the Actions (see next section), the scientists provided the evidence and technical expertise to support the document.

Forty one responses were received, including one in confidence and the feedback was largely positive. This number was considerably more than expected and was fairly equally spread across a number of stakeholder groups including government and public agencies, local authorities, environmental NGOs, Industry and Research bodies. This diversity of stakeholder in all probability reflects the multi-dimensional aspects of soil and its relationship with so many aspects of life.

Space does not permit a detailed synopsis of the feedback but among the key points were:

- Excellent overall support for the need for and co-ordinating principles within the Framework.

- *Positive* soil management a key factor running through the responses; soil protection should be enabling rather than restricting.

- More detail was required on roles, responsibilities, delivery mechanisms, targets and timescales.

The Scottish Soil Framework

The Scottish Soil Framework was published in May 2009 (Scottish Government 2009). The general content of the consultative Framework did not change radically although the order of the chapters was restructured to make them more intuitive and flow more logically. The Framework sets out the rationale for 'Actions' on Scottish Soils by describing their diversity, the functions that they perform and the benefits they deliver, the pressures on them (including climate change) and the suite of policies that currently protect them.

The Scottish Soil Framework

May 2009

The Scottish Government

Figure 1. The Scottish Soils Framework.

The key component of the Framework is the suite of *Actions* and their role in delivering Soil *Outcomes.* The outcomes were broadly accepted in the consultation, with two added and some of the original eleven subtly reworded to add some nuances that some consultees thought important, adding weight to some of the outcomes.

The *Outcomes* in the Scottish Soil Framework are:

- SO1 - Soil organic matter stock protected and enhanced where appropriate.
- SO2 - Soil erosion reduced and where possible remediated.
- SO3 - Soil structure maintained.
- SO4 - Greenhouse gas emission from soils reduced to optimum levels.
- SO5 - Soil biodiversity as well as above ground biodiversity protected.
- SO6 - Soils making a positive contribution to sustainable flood management.
- SO7 - Water quality enhanced through improved soil management.
- SO8 - Soil's productive capacity to produce food, timber and other biomass maintained and enhanced.
- SO9 - Soil contamination reduced.
- SO10 - Reduced pressure on soils by using brownfield sites in preference to Greenfield.
- SO11 - Soils with significant historical and cultural features protected.
- SO12 - Knowledge and understanding of soils enhanced, evidence base for policy review & development strengthened.
- SO13 - Effective coordination of all stakeholders roles, responsibilities and actions.

The 39 agreed *Actions* built on the Future Activities in the Consultation document. They are grouped into eleven topic areas, some very specific such as Water Quality and Flooding and Cultural Heritage whereas others are more general including Climate Change and Land Use and Management. A key element of each action is they have a deadline, they link directly to the Soil Outcomes and they are attributed to one or more 'owners' i.e. those responsible for their delivery. A key and positive aspect is that all the Actions appear in the same document and all 'owners' are aware of other's Actions. This should reduce the potential for duplication and/or incompatibilities.

Some examples of their structure are given in Table 1 below.

Action	Detail	Delivery Date	Related Soil Outcome	Owner
Knowledge exchange and awareness raising				
State of Scotland's Soil report 2011	The Scottish Government will support SEPA in publishing a State of Scotland's Soils report in partnership with external organisations in 2011.	By 2012	*Primarily*: All Outcomes	SEPA, SNH, SG Soils Team in conjunction with Soil Focus Group, Main Research Providers
Land use and management				
Stump harvesting guidance	Publish interim guidance on site selection for stump harvesting	2010	*Primarily*: Outcomes 1,2,3,4, 5,6,7 and 8	Forestry Commission Scotland
Conservation & Biodiversity				
Peat protection	Scottish Government together with key stakeholders will consider ways to co-ordinate peat protection and restoration in Scotland.	ongoing	*Primarily*: Outcome 1,4, 5 *Secondary:* Outcomes 2,13	SG Soils Team in conjunction with Soil Focus Group

Table 1. Examples of Actions in the Scottish Soil Framework.

To ensure continuity of activity and to maintain contact between different interest groups after publication of the Framework, a Soil Focus Group was formed. The overall aim of the Group is to bring together the key delivery partners and stakeholders in the Scottish Soil Framework, and to advise the Scottish Government on the Framework's implementation. The Group was established as an informal forum with members invited onto the Group by the Scottish Government. The frequency of meetings was not predetermined but 'will convene at regular intervals' based on a needs basis. The real value of the Group was to help create networks and contacts and to share information **between** meetings; only so much business can be carried out during meetings.

Outcomes of Actions in the Scottish Soils Framework

In general, **Activities** are relatively straightforward to monitor and measure but the **Outcomes** and success of **those** can be more difficult. Nevertheless, a positive report on many of the Actions of the Framework was published on the 10th December 2013 to coincide with the launch of Scotland's Soils website (which itself is a positive outcome of one of the Framework Actions) http://www.soils-scotland.gov.uk/. It is not possible to report on the outcome of each of the Actions so only a selection is presented here.

Action 9 Information Availability

The initial action was 'Web delivery of soil information will be available from the National Soils database at the Macaulay Institute (now the James Hutton Institute) allowing stakeholders the ability to compare their soils with National data'. There was a perception that data were not being made widely available and thus their utility was not being exploited to the full by policy, regulators, industry, consultancies and by fellow researchers.

This has been achieved through a number of outlets both web-based and through mobile phone apps (See Figure 2). They have proved relatively popular; soil is still viewed as a relatively obscure topic. For example the SIFSS website http://sifss.hutton.ac.uk/ has had 234 downloads, the app has been used 2,500 times to request soil information since the end of 2012. The website has been used to query soils 160 times between mid June and mid August 2014. Scotland's Soils website http://www.soils-scotland.gov.uk/ has had 500 downloads since its launch in December 2013, although a number of these were return visits. A range of primary and derived datasets are available both for viewing and download. This exposure can only be good for the soil science community and may lead to additional funding to enhance existing data sources.

Soil is a complex medium and one slightly surprising aspect since the data have been widely available is the lack of requests for clarification on what the data actually are. Metadata are provided and further information can be found in the website libraries and these are proving sufficient for most users to use the data for their specific needs.

Action 10 Scottish soil monitoring network

Although Scotland is relatively data rich in terms of soil data, a number of reports have recognised that there is a lack of trend data to illustrate how soils may be changing. There are serious considerations with soil monitoring notably its short range heterogeneity, changes in analytical techniques, differences in field sampling procedures, logistics and costs. As a result progress on this action has been slower, but a Soil Monitoring Action Plan (SoilMAP) has been developed by a subgroup of the Soil Focus Group. Key features of it include:

- There is an explicit link to soil functions; we are not monitoring as an academic exercise, we are doing so to ensure that soils still have the ability to perform a range of functions.

- There is also an explicit link to the soil outcomes in the Scottish Soils Framework.

- Links to different policies have also been identified to monitor the effectiveness of measures.

- Different organisations have responsibility for different parts of the Plan dependent on their expertise and remit. This is a similar approach to that of ‘ownership’ of Actions in the Scottish Soils Framework.

- A number of short range tasks have been identified and timetabled. In most cases, they are linked to ongoing activities and some stray from the more conventional approaches to soil monitoring, e.g. catchments walks along water courses to identify bank erosion and other evidence of soil movement to water.

The SoilMAP is one of a series of plans being developed by the Coordinated Agenda for Marine, Environment and Rural Affairs Science, 2011-2016 (CAMERAS) Monitoring Coordination Group and is one of the more advanced in terms of planning.

Action27 Peat Protection

Peat (defined in Scotland as a soil with a surface horizon with more than 60% organic matter and more than 50 centimetres deep) is Scotland’s most extensive soil type, covering approximately 20% of its land surface. Much of it is blanket peat with its distribution conditioned by the cool moist climate that favours organic matter build up at the soil surface. There are also areas of basin peats but they are much less extensive.

The status of peat in a policy context has risen markedly in recent years primarily in the Climate Change agenda and its role as a carbon store. It has been valued for its support for bog habitats and the avian species it sup-

Figure 2. Making soil data available using mobile phone technology.

ports and as a commercial and domestic source of fuel; it is safe to say that a large proportion of the Scottish public remain unaware of its true value.

The peat resource of Scotland has been subjected to a range of pressures over many decades but most notably in the second half of the 20th century. These include burning, atmospheric pollution, over grazing and significantly efforts to drain the peat for agriculture and forestry. Some of the impacts can be quite dramatic (Figure 3) A growing body of evidence emerged that indicated that these activities meant that many bogs were not functioning properly and had become net emitters of Greenhouse Gases.

Given the importance of peat in the climate change debate, the Scottish Government has committed £16m to peat restoration projects to 2016. The influence that the Soil Framework and Soil Focus Group had on securing this investment

Figure 3. A peat slide in Shetland 2003; photograph taken in 2009.

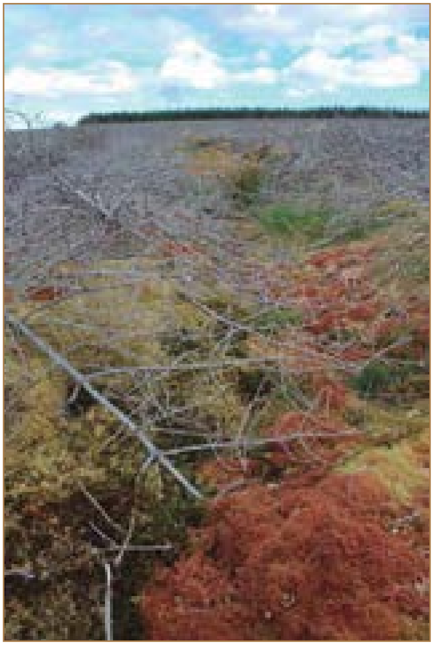


Figure 4. Peatland restoration following afforestation in North Scotland.

cannot be determined with any accuracy, but the very existence of this Action raised the profile of peat in the policy agenda. The debate continues on the choice between peat restoration or woodland restocking on degraded peat (Figure 4). Further initiatives on this Action (and the others) can be found at the weblink below: http://www.soils-scotland.gov.uk/documents/115131209_Scottish_Soil_Framework_%28SSF%29_Progress_Report.pdf.

Action 34 Identify soil management practices that optimise soil carbon sequestration

This has become a key component of the soils agenda globally and although Scottish soils, even those under arable crops, generally have adequate levels of organic carbon, we cannot be complacent. A number of significant developments in research, policy and extension activities have occurred during the lifetime of the Framework. These include:

- There has been no major change in total soil carbon stocks over the last 25-30 years. There have been changes within specific land uses (Chapman *et al.* 2013).

- Evidence of GHG loss from woodland planting on peat has led to a policy precluding any new planting on that resource.

- The Farming for a Better Climate Initiative has provided real world experience of adaptation to climate change including sustainable soil management. More details at: http://www.sruc.ac.uk/info/120175/farming_for_a_better_climate.

The contribution of land use to a low carbon society has been the subject of a number of studies and reviews, for example by the Royal Society of Edinburgh (Campbell *et al.* 2012). There is also increasing evidence that below ground biodiversity (i.e. in the soil) has a key role in determining the ecological and evolutionary responses of terrestrial ecosystems to current and future environmental change (Bardgett and van der Putten 2014); the increasing recognition of the importance of soil in a changing environment is to be welcomed.

The Scottish Land Use Strategy

Soils remain high on the political agenda, notably as part of the Scottish Land Use Strategy (Scottish Government 2011) http://www.scotland.gov.uk/Topics/Environment/Countryside/Landusestrategy which already deals with a number of soil issues and, in a sense, there is a logic for soils to be handled in a more holistic way as part of land. To an extent, this mirrors developments in Europe after the withdrawal of the proposed Soil Framework

Directive and the upcoming Communication 'Land as a Resource' which is likely to include several elements from the proposed Directive (http://ec.europa.eu/environment/land_use/index_en.htm).

The Land Use Strategy is part of the Climate Change (Scotland) Act 2009 and brings together proposals for getting the best from Scotland's land resources. It contains:

- Three underpinning objectives related to business and economic growth, stewardship of Scotland's natural resources and community involvement and deriving benefits from the land.

- A set of ten principles for Sustainable Land Use.

- Thirteen proposals grouped under the three underpinning objectives. These proposals are not mutually exclusive nor are the Objectives.

The proposals that relate to soil fall primarily under the stewardship of Scotland's natural resources objective although the one reported here is within the business focussed objective.

The Scottish Land Use Strategy: Proposal 7

This proposal reads 'Identify more closely which types of land are best for tree planting in the context of other land-based objectives, and promote good practice and local processes in relation to tree planting so as to secure multiple benefits'. It follows the Forestry Commission publication 'The Right Tree in the Right Place' in 2010. Both statements imply that in the past that species choice did not always necessarily match site conditions. However we must be wary of being over critical of past decisions when objectives and priorities were different; unintended consequences are never deliberate.

Since 2006 when the Scottish Forestry Strategy was revised, there has been an aspiration to have 25% woodland cover over the Scottish Landscape by 2050. A Woodland Expansion Advisory Group (WEAG) was established by the Scottish Government to advise them, amongst other objectives, which types of land are best for tree planting in the context of other land use objectives. To help them achieve this, the James Hutton Institute and Forest Research were commissioned:

- To determine the impact of various constraints on the availability of land for woodland expansion.

- To identify the types of land most appropriate for woodland expansion after consideration of the above.

The project was conducted in three phases and based on identifying the range of different constraints on woodland expansion. By implication, there is recognition that the soils on constrained land are more valued for other functions. A GIS screening procedure was implemented and this is outlined briefly below.

Phase 1. Land that is predominantly not available for woodland expansion

The various types of land included in this phase of the analysis are (with the implied preferred *soil function* in parenthesis):

- Current woodland *(providing the basis wood and biomass production;* clearly land currently wooded is not available for woodland expansion).
- Land biophysically and biologically unsuitable for planting *(providing valued habitats & sustaining biodiversity.* Includes high altitude and very rocky land for example).
- Built up land *(providing a platform for buildings and roads).*
- Prime agricultural land (Land Capability for Agriculture classes 1 – 3.1) *(providing the basis for food).*
- Areas of peat deeper than 0.5 metres *(storing carbon and maintaining the balance of gases in the air; providing valued habitats and sustaining biodiversity).*

When these areas are combined, the total area that is not available for new woodland amounts to almost 3.6 million hectares (46% of Scotland's land area); 31% is constrained by biophysical/biological factors, 15% by current policy. It is unlikely that policy on prime land and peat will change in the foreseeable future. It is recognised that built up and prime agricultural land will have valuable but very limited potential for new woodland in the context of national expansion targets.

Phase 2. Land that is affected by national designations and policies which impose varying degrees of constraint on woodland expansion

In this phase, land with a conservation designation was identified, excluding areas already identified in Phase 1. Large areas of Scotland are designated because of their open ground habitat and associated fauna and many have multiple UK and European designations. It is acknowledged that there are smaller areas designated for their woodland interest, notably native Scots Pine woodlands but also others such as the Atlantic Oakwoods of the western seaboard. The *providing valued habitats and sustaining biodiversity* soil function is implied here.

National Scenic Areas, identified for landscape protection and enhancement objectives, have less statutory influence on land use decisions but nevertheless there are a number where new woodland would be seen in a negative light. On the other hand, there are others where woodland plays a vital role in landscape quality and where sensitive expansion would be encouraged. These are factors for local decision making. The *providing valued habitats and sustaining biodiversity* soil function is also implied here.

There are also a small number of catchments at risk of acidification *(regulating water flow and quality* function) and new woodland would compromise the integrity of some key heritage sites (*preserving cultural and archaeological heritage* function).

When the areas covered by these categories of land are combined, they total approximately 1.6 million hectares (20% of Scotland).

Phase 3. Land that provides most opportunities for woodland expansion

This is in effect is the land that remains after the sieving analysis outlined above. In round numbers, this amounts to approximately 2.5 million hectares (34% of Scotland). A wide range of land use categories are found here, but they can be summarised in four broad categories:

- Mixed arable land with mineral soils.

- Improved grassland with mineral soils.

- Semi-natural grassland with mineral or soils with shallow organic horizons (organo-mineral soils).

- Dwarf scrub heath with organo-mineral soils.

Clearly where trees are actually planted is down to land owner choices and local decision making processes including the planning system. A national screening cannot determine precisely where trees will go but at a strategic level, it does provide an objective indication, using robust data, of the national picture.

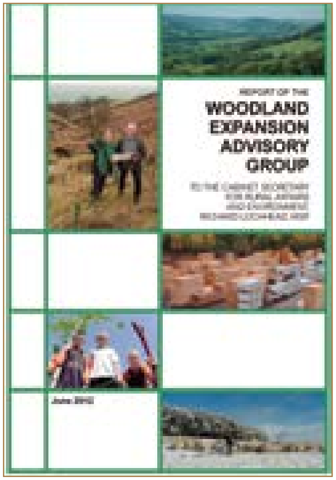
The work was well received and the principal benefits to the WEAG were:

- It established a key landmark in the Group's discussions.

- All parties agreed in principle that the overall findings were robust at the Scotland wide scale.

- It provided a way forward for more detailed discussions.

By identifying what types of land are most suited to woodland expansion, it became clear that a greater degree of integration of farming and forestry was required. A significant proportion of this land is under arable or grassland production and that it would have to contribute to woodland expansion targets. Significantly, the Group decided at any early stage that the 25% aspiration of woodland cover by 2050 should be dropped and replaced by shorter term woodland expansion targets; it was seen as too long term and in a sense almost became a target without any real objectives. More information can be found in the final report to the Scottish Government (Woodland Expansion Advisory Group 2012) (Figure 5) http://scotland.forestry.gov.uk/images/corporate/pdf/WEAGFinalReport.pdf.



REPORT OF THE

WOODLAND
EXPANSION
ADVISORY
GROUP

June 2012

Figure 5. Recommendations for woodland expansion in Scotland.

Concluding Remarks

The Scottish Soil Framework (SSF) is the first explicit political recognition that 'Scotland's soils are one of the Nation's greatest assets'; ministerial support for a subject that is not often in the public or political consciousness represents a significant move forward. The Framework was developed in response to a complex policy and regulatory landscape as soil impinges on many policy areas; it was not intended to replace or create new policies or regulations but to encourage greater co-ordination between existing ones. It was also designed to increase dialogue between relevant stakeholders and continue the interaction with the research community, building on existing relationships. The forum for this was the Soil Focus Group.

The Framework has helped raise the status of soils in other policy areas of Government. For example the use of land for new building and transport infrastructure ('soil sealing') has been the subject of discussion at the EU in Brussels and the situation in Scotland is no different; economic growth and demographic changes in our population means more land is being developed and it is often on high quality agricultural land. This has been recognised in Planning and Scottish Government Planning Policy (2014) Section 80 states 'Development on prime agricultural land (LCA classes 1, 2 and 3.1), or land of lesser quality that is locally important should not be permitted except where it is essential'. In 2001, the presumption against development on this type of land was removed but the issue was brought to the fore in the Framework and subsequent discussions.

Similarly, the role of peatlands in Scotland's climate change mitigation strategy was highlighted in the Framework and subsequent briefing notes and workshops, for example http://www.scotland.gov.uk/Resource/Doc/921/0109512.pdf. The Scottish Government has since committed £16 million to peatland restoration up to 2016; the direct role of the Framework in achieving this is unclear, but at the very least it raised the profile of peatland in the climate change debate which eventually led to this scale of investment and action on the ground.

One of the Actions of the Framework was to raise awareness of Soils across a range of stakeholders, including the general public. This action has prompted a number of outreach activities that has helped raise awareness, often using quite novel techniques. This in turn has led to Scottish based soil scientists being invited as plenary speakers at International conferences and being actively involved in European and Global initiatives, including the Global and European Soil Partnership.

The importance of soil **management** in maintaining soil function prevails through the Framework and the Land Use Strategy. This is recognition that active and positive management can help rectify previous damage, but it also recognises that policy objectives can change radically over quite short timeframes, for example on our peatlands. People also react more positively to activity than they do to restrictions. Sustainable management of our soils is driven by concerns such as climate change and water quality as well as of the soil *per se* and demonstrates that soil is at the centre of the sustainable development paradigm.

At the time of writing (December 2014) it is proposed that much of the Soils agenda in Europe will be addressed in the consultation Communication on "Land as a resource" (http://ec.europa.eu/environment/land_use/index_en.htm). This mirrors the Land Use Strategy, where similar positive actions are being proposed to ensure our soils contribute to our economic, environmental and social well-being.

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References

Bardgett, R. D, and van der Putten, W. H. 2014. Belowground biodiversity and ecosystem functioning. Nature, 515, pp 505 – 511.

Campbell, C.D.; Lilly, A.; Towers, W.; Chapman, S.J.; Werritty, A.; Hanley, N. 2012. Land use and a low-carbon society. Earth and Environmental Science Transactions of the Royal Society of Edinburgh, 103, 165-173.

Chapman, S.J.; Bell, J.S.; Campbell, C.D.; Hudson, G.; Lilly, A.; Nolan, A.J.; Robertson, A.H.J.; Potts, J.M.; Towers, W. 2013. Comparison of soil carbon stocks in Scottish soils between 1978 and 2009. European Journal of Soil Science, 64, 455-465.

Scottish Government. 2008. The Scottish Soil Framework. A Consultation Document. The Scottish Government 2008.

Scottish Government. 2009. The Scottish Soil Framework. The Scottish Government 2009.

Scottish Government. 2011. The Scottish Land Use Strategy. The Scottish Government 2011.

Scottish Government (2014) Scottish Planning Policy The Scottish Government, June 2014.

Towers, W., Grieve, I.C., Hudson, G., Campbell, C.D., Lilly, A., Davidson, D.A., Bacon, J.R., Langan, S.J. and Hopkins, D.A. 2006. Scotland's soil resource - current state and threats. CRF Report to SEERAD. http://www.scotland.gov.uk/Publications/2006/09/21115639/0.

Woodland Expansion Advisory Group. 2012. Report to the Cabinet Secretary for Rural Affairs and Environment.

Summary and Conlcusions

What can be concluded from the FORRISK workshop?

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Following the keynote speech by L. Montanarella, major soil degradation risks in Europe can be organised into four major groups: chemical degradation (contamination, salinization and acidification), physical degradation (mostly soil compaction), biological degradation (loss of biodiversity and destruction of humus or organic matter decline) and soil loss in two distinct ways, namely erosion and sealing. These processes are in many cases inter-related and are in most cases related to the reduction of the soil fertility (through nutrient depletion and reduced physical fertility). As a result of these problems taking place in many regions of Europe, the ability of soils to adequately deliver their environmental and socio-economic services is reduced in many areas.

The regional cases presented in the FORRISK Workshop, reporting degradation risks and/or prevention programs in different zones of Western Europe provide a good overview when assessing the situation of forest soils in relation to these soil degradation problems in the area.

Among those cited above, the four most significant and most frequently cited soil degradation issues were soil erosion, organic matter decline, acidification and nutrient depletion, and, to a lesser extent, soil contamination. The significance and intensity of these problems varied widely between regions.

Soil erosion and related issues seem to be the most significant soil degradation problem in Iceland, and together with the nature of Icelandic soils, it is mostly related to historical deforestation and overgrazing. Erosion is also important in the Basque Country, where most forest soils occur under managed forest plantations. Erosion is indeed the only aspect of soil conservation in relation to forest soils accounted for in the legislation in this region. Erosion can also be important in Galicia, especially after fire events. However, the problem was reported to be less intense in the UK, Ireland and Aquitaine at present. In the UK and Ireland it has been successfully controlled with forest management practices. In Aquitaine, the planted forests in the Landes triangle have contributed to the reduction of erosion rates. This could change if changes in land uses imply a reduction of the forested area.

The **loss of organic matter** is a major concern in afforested peat soils in Ireland and the UK, as well as in Galicia, for different reasons (afforestation and uncontrolled fires). It has been observed and quantified in forest soils in the Basque Country, in this case caused by some intensive forest management techniques. In Aquitaine, as for soil erosion, organic matter levels remain stable in forest soils, but could decline if land uses change.

Some forest soils in Aquitaine – in particular in the Landes forest range – have however shown problems with **nutrient availability**, especially P, as it seems to be the case in Ireland. While in Aquitaine the nature of soils can explain this problem, in Ireland it seems mostly related to low fertility of some soils. In the Basque Country and Galicia, nutrients have been observed to be lost together with organic matter when this occurs. A common observation in all regions is that the risk of nutrients losses increases as forest management becomes more intensive.

Finally, **soil contamination** is still a minor issue in most regions, but could become important if diffuse contamination and contamination from soil amendments continue.

In addition to these soil degradation problems related to soil management, some regional cases also highlighted the importance of **soil sealing** and land take as a major issue in relation to the reduction of forest soils and their capacity to function properly. As in the previous cases, the significance of the problem varies widely across regions. It is not significant in Iceland, with a very low population density, but is important in the Basque Country, where the high population density and the attribution of valley and river-plains soils to other uses have pushed forestry to steep slopes.

All in all, an overview of these soil degradation problems points to the conclusion that they are inter-related (for instance, less organic matter can increase soil erosion), site-specific and in most cases, related to forest and land management. These regional differences indicate thus that soil degradation has different causes, intensities and consequences across the different regions. They also indicate that a number **of cross-cutting issues** can be identified in relation to forest soils degradation.

First, **land-use conflicts** are at the origin of some soil degradation problems. Some examples are the potential conflicts between recreational and touristic aspects and forests (Iceland), agriculture and forests in a context of increased demand for food (ex. maize cropping in Landes), or urbanisation and forests (which is at the origin of the occupation of marginal land by planted forests in the Basque Country). There is therefore evidence of a need to identify priorities for land use, with a particular emphasis on establishing or maintaining forests on the soils better suited for this use. A good example of this was given by the land-use strategy under development in Scotland.

Second, it becomes evident that no universal solution exists for problems that are clearly **site-specific**. For instance, afforestation, which is a common strategy in forest policy, seems an adequate solution for soil degradation problems in Iceland, but not the best practice for all soils in Ireland and the UK. Afforestation of peatlands can lead to significant losses of soil organic matter and soil quality. In Galicia, it has been observed to be responsible for the decline of soil fertility. Site-specific assessments and solutions are therefore needed for forest soil degradation problems in the region. Some examples of this type of strategies, where the recommended management practice is selected as a function of the soil type, can be found in the practice guides developed under the UK Forestry Standard.

Third, many of the soil degradation problems described are expected to be affected by **climate change**. In a context where storms can become more frequent, intense and unpredictable, forest fires can increase and the availability of water may change in some regions and windthrow may be more frequent and severe. The development of mitigation and adaptation strategies seems crucial.

Fourth, it can be concluded from the regional case-studies, that changes in forest **management towards more intensive systems** (for example biomass production for energy generation) has consequences for soil degradation (nutrient depletion, soil organic matter loss, productivity, etc.). A widespread case that deserves particular attention is the implementation of short-term rotations with fast-growing species and intensive harvest systems (non-stemwood and stump removal). As for the case of land-use conflicts cited above, there is a need to prioritise the services demanded of forests, by contrasting economic revenues with ecological services. An example of a partnership for drinking water protection in the French Alps showed that soil protection was a key factor for good water quality of forest springs.

Finally, all regional cases stressed the need for the **development of soil monitoring networks** that include the identification of risk areas for forest soils degradation. This is linked to the need for more problem-solving research, which according to our previous reasoning, should be developed in collaboration with policy makers and land users, in a multi-actor and multi-target framework.

Considering these aspects, the following **conclusions** can be drawn from the works presented in the conference:

- First, a **comparative analysis** such as the one offered by the presentation of multiple regional cases is a fruitful and promising strategy on the way towards better forest soil protection.

- Second, there is a need for a **common framework for forest soil quality evaluation** and research. In this sense, cross-sectorial and multi-actor networks should be encouraged and developed.

- Finally, it became evident from the multiple cases presented, that there is a need for some **trans-national harmonisation and development of forest soil protection policies** and policy actions in Europe, which should comprise the environmental services of soils.