**Forest vegetation management - towards environmental sustainability**

**Proceedings from the final COST E47 Conference, Vejle, 2009**

Bentsen, Niclas Scott

# Forest Vegetation Management
# – Towards Environmental Sustainability

**Proceedings from the final COST E47 Conference**
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Niclas Scott Bentsen (Ed.)

# Foreword

Successful afforestation and forest regeneration requires young tree seedlings to be protected from vegetation that may compete for scarce resources such as water, nutrients and light. In recent years forest managers have come to rely on herbicides as the cheapest and most efficient means of controlling this competing non crop vegetation.

In Europe there is and increasing political and public debate about pesticide use within forests, due to concerns about potential impacts on groundwater, biodiversity and human health. Government and European Union regulation and voluntary forest certification schemes aim to encourage a reduction and in some cases an eventual elimination of pesticide use within woodlands.

However, adequate alternatives to herbicides do not currently exist for many of Europe's forest conditions. Without the knowledge or technology to implement efficient alternatives, forest managers' ability to protect and regenerate both natural and plantation forests will be severely threatened.

COST E47 was initiated in 2005 and has gathered experts from 19 European countries representing academia, research and management within the field of forest vegetation management. The main objective of the COST-Action is to gradually reduce dependence on herbicides in Europe's forests by developing alternatives that are based on sound forest management principles, recognize society's need for the sustainable production, and employ methods that are environmentally sound, socially acceptable, and economically viable. A key benefit of the Action is the establishment of a European forum for the management of forest vegetation, where co-operation between the main players in the forest industry in Europe together with the scientific institutions is intended to give leadership and create networks providing data and information for national forest services and the public. More information can be found on the action web site: http://www2.clermont.inra.fr/cost-e47/.

These proceedings are a collection of abstracts from the final COST E47conference on forest vegetation management hosted by Forest & Landscape, Faculty of Life Sciences, at the University of Copenhagen. The conference was held in Vejle 5-7 May 2009 and gathered people from Africa, Canada and Europe.

# COST

COST – the acronym for European Cooperation in Science and Technology – is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST – less than 1% of the total value of the projects – support the COST cooperation networks (COST Actions) through which, with EUR 30 million per year, more than 30 000

European scientists are involved in research having a total value which exceeds EUR 2 billion per year. This is the financial worth of the European added value which COST achieves.

A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "à la carte participation" (only countries interested in the Action participate), equality of access" (participation is open also to the scientific communities of countries not belonging to the European Union) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains such as: Biomedicine and Molecular Biosciences; Food  and Agriculture; Forests, their Products and Services; Materials, Physical and Nanosciences; Chemistry and Molecular Sciences and Technologies; Earth System Science and Environmental Management; Information and Communication Technologies; Transport and Urban Development; Individuals, Societies, Cultures and Health. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

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# Content

# FSC certification processes and their impact on forest vegetation management

*Marion Karmann 1), Frank Katto 1)*

1) Forest Stewardship Council FSC International
Charles de Gaulle Str. 5
D-53113 Bonn, Germany
m.karmann@fsc.org

**Key words**
FSC certification, forest management, FSC, stakeholder consultation.

**Introduction**
Since the 1980s the community of scientific researchers has pointed out that complex relationship between the natural functioning of forest ecosystems, forest utilization, and the people involved is drastically under stress. B. Cashore et al. (2006) summarized "In the face of this body of knowledge and the consensus that many problems are intensifying, domestic and international governmental responses have been strongly criticized as woefully inadequate and far too slow to address the myriad problems facing global forest management (FM). As a result of this frustration, some of the world's leading environmental groups and their allies decided to sidestep governments and in 1993 created the Forest Stewardship Council (FSC). FSC and its supporters turned to the marketplace to generate incentives for forest businesses to conform to environmentally and socially responsible forest practices. The solution put forward by FSC was relatively simple: develop a set of global sustainable forestry principles and criteria, have national and subnational multistakeholder committees, develop regionally appropriate standards, have third parties audit forestry operations for compliance, and certify those who pass the test - providing a badge of honor that, the hope was, would allow certified operations to gain some type of market advantage vis-à-vis their competitors (…)." These multi-stakeholder committees on the national and international levels can be regarded as FSC's strongest asset in developing meaningful standards for responsible forest vegetation management. On the environmental side environmental NGOs like WWF, Greenpeace, The Nature Conservancy and Friends of the Earth are providing strong input into the indicator development and, observing carefully the full implementation of these standards.

The FSC logo has become a powerful incentive for forest managers and decision makers to improve their forest management continuously: To date, FSC has certified about 1'000 forest management units with a total of 107 million hectares of forest worldwide, and FSC is regarded as a major policy driver with regard to forest management practices including the stringent requirements on the use of pesticides in forestry. In about 60 countries worldwide, people with very different requirements and expectations regarding forest management are negotiating how they define responsible forest management, to fill the framework of the 10 global FSC Principles with criteria and indicators applicable for their own countries and regions. About 30 sets of national or regional criteria and indicators (standards) are endorsed by FSC, the majority of them for forest management in general; some for certain forest products only. In countries without endorsed national standards, the currently 18 accredited certification bodies are evaluating the forest management of the FSC certificate holders against generic standards.

**FSC regulations and recommendations regarding vegetation management:**
The FSC Principle and Criteria (P&C) (FSC-Standard 01-001), with their global applicability are by nature quite broad. Principle 6 on environmental impact requires that: "Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest." Criteria under this principle require:
" 6.1 Assessment of environmental impacts shall be completed - appropriate to the scale, intensity (…) and adequately integrated into management systems. Assessments shall include landscape level considerations as well as the impacts of on-site processing facilities. Environmental impacts shall be assessed prior to commencement of site-disturbing operations.
6.2 Safeguards shall exist which protect rare, threatened and endangered species and their habitats (…). Conservation zones and protection areas shall be established (….).
6.3 Ecological functions and values shall be maintained intact, enhanced, or restored, (…).
6.4 Representative samples of existing ecosystems within the landscape shall be protected in their natural state and recorded on maps (…).
6.5 Written guidelines shall be prepared and implemented to: control erosion, (…).
6.6 Management systems shall promote the development and adoption of environmentally friendly non-chemical methods of pest management and strive to avoid the use of chemical pesticides. WHO Type 1A and 1B and chlorinated hydrocarbon pesticides; pesticides that are persistent, toxic or whose derivatives remain biologically active and accumulate in the food chain beyond their intended use; as well as any pesticides banned by international agreement, shall be prohibited. If chemicals are used, proper equipment and training shall be provided to minimize health and environmental risks.
6.7 Chemicals, containers, liquid and solid non-organic wastes including fuel and oil shall be disposed of in an environmentally appropriate manner at off-site locations.
6.8 Use of biological control agents shall be documented, minimized, monitored and strictly controlled in accordance with national laws and internationally accepted scientific protocols. Use of genetically modified organisms shall be prohibited.
6.9 The use of exotic species shall be carefully controlled and actively monitored to avoid (…) .
6.10 Forest conversion to plantations or non-forest land uses shall not occur, except (…)."

Related specifically to the management of plantations, criterion 10.7 requires that: "Measures shall be taken to prevent and minimize outbreaks of pests, diseases, fire and invasive plant introductions. Integrated pest management shall form an essential part of the management plan, with primary reliance on prevention and biological control methods rather than chemical pesticides and fertilizers. Plantation management should make every effort to move away from chemical pesticides and fertilizers, including their use in nurseries. (…)." Chemicals are defined by FSC as "range of fertilizers, insecticides, fungicides, and hormones used in FM." The P&C are currently being reviewed publicly, with strong participation of ENGOs.

The German FSC standard for example requires "6.6.2 In principle, chemical biocides and biological control agents are not used. Exceptions are official pest-control orders. In this case, the certifier is notified prior to the biocide application. The rationale for the use of biocide is provided and the biocide application is documented for subsequent review. The date of the biocide application and the date of the timber sale will be verified. Where alter-

natives exist, biological control agents (eg. BT-preparations) are preferred. (…) Wood which has been treated with chemical biocides may only be marketed as FSC-certified after six months have elapsed from the date of the final biocide application." Stipulating that pesticides may not be applied at all would conflict with FSC's "Principle 1: Forest management shall respect all applicable laws of the country in which they occur (…)." Other national standards are not necessarily that strict, but they cannot require less than the FSC P&C. These criteria are valid worldwide for FSC certified forests as minimum requirements. National and generic criteria must not weaken the intention of the FSC P&C.

### FSC Working Groups and research resources on vegetation management and pesticide use:

A diverse range of multi-stakeholder committees has evolved over the past years in several countries, responding to the need to locally adapt the FSC P&C. These committees comprise forest managers, practitioners and researchers, and environmentalists. For each FM unit, certification stakeholders are consulted to give them the opportunity to be informed and to react on the vegetation and pesticide management plans. To connect and to enable these stakeholders to get a full picture of the range of options for good management, FSC offers relevant information on the website. Additionally FSC hosts a number of electronic fora, e.g. for auditors, national initiatives, and certificate holders, to disseminate respective information.

### FSC Pesticides Policy

In May 2005 FSC began to review its FSC Pesticides Policy (unchanged since 2002) with regard to forest and plantation management. This has been a major subject of discussion focusing on the pesticides that are considered as "highly hazardous" and therefore restricted for use on FSC-certified lands. To provide consistent, international guidance for the implementation of these requirements, the FSC installed an expert panel to develop guidance documents to the pesticide policy, based on multi-stakeholder and expert consultations. Also useful to this process is the voluntary formation of a group with over 50 companies and organizations from Canada, Australia, New Zealand and the US (CANZUS group) with the aim of improving the methods for forest pest management. In Brazil, an example of FSC's impact can be seen, where mosaic patterns are now used in plantations to drastically improve biodiversity and to reduce the use of pesticides.

Outlook: Implementation of vegetation management practices
FSC is considering developing an online resource center, where forest managers can deposit and share any good practices of forest pest and vegetation management. The goal would be to have information on a) successful vegetation control practices at the regional levels b) successful control measures locally but being tested at wider scale. However, arriving at both goals will require financial resources and scientific peer reviews.

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# Trends in Forest vegetation management in Europe in the 21$^{st}$ century

*Nick McCarthy*

The European Network for Co-operation in the field of Science and Technology (COST) funds the development of scientific networks of excellence on a wide variety of topics and disciplines. COST Action E47, part of the Forestry Domain, was formed in 2005. It has brought together practitioners and scientists from 19 European countries to share expertise and experience and the latest scientific advances in the field of forest vegetation management

The aims of this paper are:

- to provide a summary of the current 'state of the art' as it applies to forest vegetation management in Europe for scientists, practitioners and policy makers, whether they are affiliated to state, non-governmental or private commercial organisations;
- to document existing control practices across Europe, and hence provide information on alternative solutions for individual countries sharing similar conditions and challenges;
- to identify common information gaps and future research needs, and hence potential future areas of collaboration for forest vegetation management scientists across Europe, along with barriers that may need to be overcome to achieve that aim.

This paper will provide for the first time an overall review of forest vegetation management as it is practised across nineteen European countries in the early twenty first century.

# Long-term response of weed control intensity on Scots pine and Norway spruce survival and growth on arable land

*Jyrki Hytönen* and *Paula Jylhä*

Finnish Forest Research Institute, Kannus Research Unit, P.O. Box 44, FI-69101 Kannus, Finland.
jyrki.hytonen@metla.fi, tel. +358-102113405, fax +358-102113401

**Key words**
Vegetation control, seedling type, Norway spruce, Scots pine

## Introduction

Since 1969, more than 250 000 ha of agricultural fields have been afforested in Finland (Peltola 2008). Norway spruce (Picea abies (L.) Karst.), Scots pine (Pinus sylvestris L.) and silver birch (Betula pendula Roth) are the most common tree species planted on abandoned fields. Although tree stands located on such former agricultural land can be highly productive, successful afforestation of agricultural fields is considered to be far more difficult than reforestation of clear-cut forestland.

Former agricultural soils are usually more fertile than conventional forest sites because of changes in soil properties caused by agricultural practices (Wall & Hytönen 2005). Consequently, vegetation on abandoned fields is more vigorous, and competes with tree seedlings for water, nutrients and light. After soil preparation, the open field is colonized by annual species germinating from the large seed banks of pioneer weeds. Subsequently, annual weeds give way to perennial herbs and grasses. Grasses often dominate the vegetation for a long time, and the species composition does not resemble forest vegetation for a long time. In the Nordic region in winter, tall grass vegetation pressed down by a thick snow layer can seriously damage tree seedlings.

The aim of this research was to investigate the long-term effects of post-planting vegetation control intensity on the growth and survival of Norway spruce and Scots pine seedlings based on 15-year data from an experiment established on arable land in Central Finland. Results on the effects of Norway spruce seedling type (bare-rooted vs. containerised) have been already published (see Hytönen & Jylhä 2008).

## Material and methods

The experiment was established in spring 1990 in Central Finland (63°45'N, 24°18'E) on rotavated and harrowed agricultural soil (see Hytönen & Jylhä 2008). Therefore, the soil was

*Table 1. Weed control treatments*

| Date of application | Intensity of weed control treatment | | | |
|---|---|---|---|---|
| | **Control** | **Low** | **Medium** | **High** |
| 19.-25.6. 1990 | No treatment | Terbuthylazine, overall application | Terbuthylazine, spot application | Terbuthylazine, overall application |
| 10.-17.6. 1991 | No treatment | No treatment | Terbuthylazine + glyphosate, spot application | Terbuthylazine + glyphosate, overall application |
| 23.-26.6. 1992 | No treatment | No treatment | No treatment | Terbuthylazine, overall application |

Application rates: Terbuthylazine (Gardoprim) 6–7 l per treated ha, glyphosate (Roundup) 3 l per treated ha.
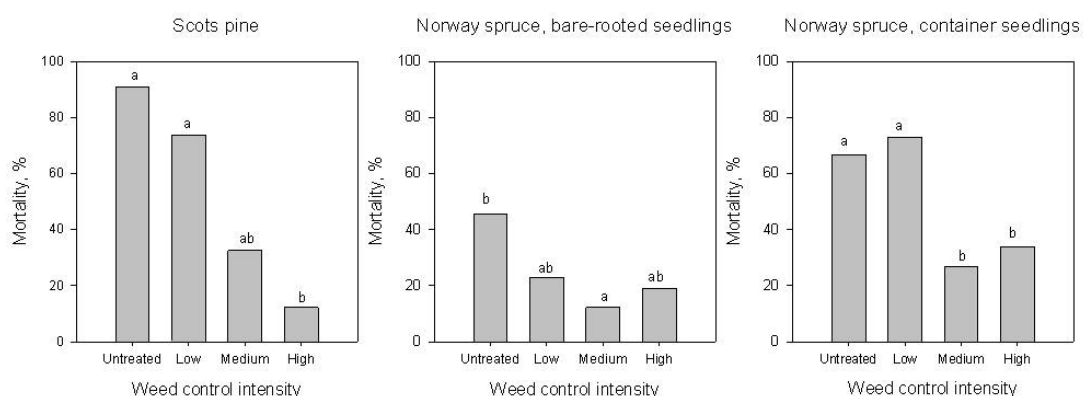
*Fig. 1. The effect of vegetation control intensity on the mortality of Scots pine and Norway spruce seedlings. Mean cumulative mortalities after the 15th growing season followed by the same letter above the bars did not differ from each other at 0.05 significance level according to Tukey's test.*

free from vegetation when planting the seedlings. Scots pine (4-year-old, bare-rooted) and Norway spruce (2-year-old container and 4-year-old old bare-rooted) seedlings were planted to a density of 3000 seedlings ha-1. After planting, four different levels of weed control intensity were tested, using soil-active terbuthylazine and foliar-active glyphosate (Table 1). The experiment was established as randomised block design with 4 replications. The height and vitality of the seedlings were recorded, and two main causal agents of damage were assessed several times during the study period (see Hytönen & Jylhä 2008). The vegetation was examined for species composition and cover percentage three times. Analysis of variance was used to test the statistical significance of the weed control treatments.

**Results**

After two growing seasons, vegetation coverage on the control plots had reached 96%. Low and high intensity treatments resulted in 87% and 8% vegetation coverages, respectively. The high intensity treatment reduced the weed coverage significantly for at least four growing seasons.

For Norway spruce, the highest stand volumes were obtained with the combination of large bare-rooted seedlings and effective vegetation control. The most intensive weed control treatments (double or triple application) increased seedlings' survival by 33–40% units (Fig. 1) and their height, breast height diameter, and volume (Fig. 2) by 45–49%, 17–47%, and 249–279%, respectively.

In the case of Scots pine, only large bare-rooted seedlings were used. On the untreated plots, 91% of the seedlings died by the end of the follow-up period, while mortality was only 12% on the plots with the most intensive weed control (Fig. 1). On these plots, increments in height, breast height diameter and stand volume were 24%, 8%, and 790% compared with untreated plots, respectively (Fig 2).

**Discussion**

Competition from ground vegetation decreased the mortality and increased growth of Scots pine and Norway spruce. Medium intensity treatment and the high intensity treatment gave the best results in terms of growth and survival. Effective weed control decreased the mortality of both bare-rooted and container seedlings, and the effect was stronger in the case of container seedlings. However, usually survival of large 4-year old Norway spruce seedlings has been reported of being rather high. According to several studies, their mortality on
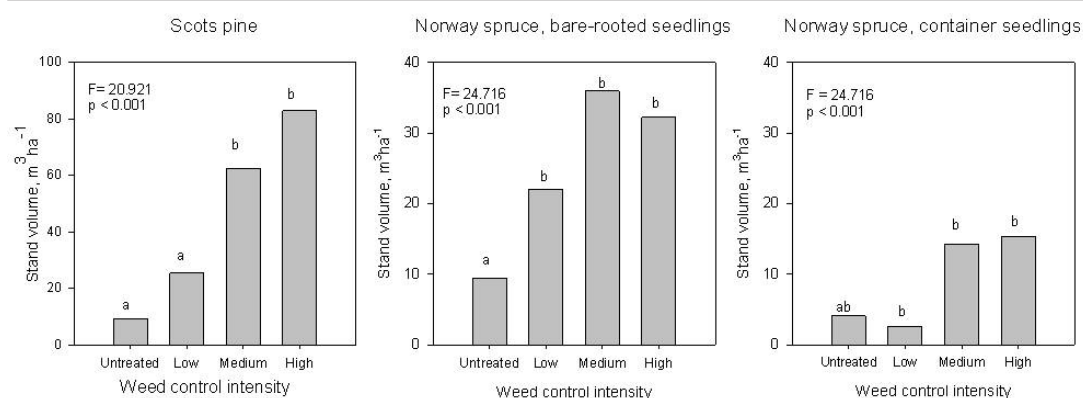
*Fig. 2. Effect of vegetation control intensity on the stand volume of Scots pine and Norway spruce seedlings after 15 growing seasons. Mean volumes followed by the same letter above the bars do not differ from each other at 0.05 significance level according to Tukey's test.*

abandoned fields (Leikola 1976, Jylhä & Hytönen 2006) and on reforestation areas (Brække et al. 1986, Kolström 1991) has been independent of weed control. However, the size of the seedlings could be an even better indicator of success in afforestation, rather than seedling type only.

Vegetation coverage of the initial stage correlated significantly with the mortality after 15 growing seasons. Therefore, controlling competing vegetation during the first few years after planting seems to be of great importance. Lund-Høie (1984) and Jylhä & Hytönen (2006) concluded that in order to get a good response to vegetation control, competition should be reduced for two or three post-planting growing seasons. In the present study, mortality started to increase markedly only when the mean vegetation coverage exceeded 70%. Similar results have been obtained earlier from Scots pine (Jylhä & Hytönen 2006) and silver birch (Hytönen & Jylhä 2005). However, Jylhä & Hytönen (2006) did not find any effect of vegetation cover on Norway spruce mortality .

Repeated herbicide applications are not recommended in Finland. This study shows that repeated application on afforested agricultural land increases growth and survival markedly. Repeated application is probably even more important with foliar active herbicides. Achieving optimal results in field afforestation in terms of success in plantation establishment, economy and ecological considerations calls for integrated vegetation management. The need for effective vegetation control has increased along with decline in seedling size due to transition into the production of containerised seedlings. At the same time, the number of herbicides available and their use in forestry in Finland has been drastically reduced. Therefore, research into of integrated and alternative means of vegetation control are of great importance.

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# Herbicide weed control in pedunculate oak (*Quercus robur*) forest regeneration

*Verica Vasic[1], Branko Konstantinovic[2], Mirjana Jarak[2], Sasa Orlovic[1]*

[1] University of Novi Sad, Institute of Lowland Forestry and Environment, Antona Cehova 13 P.O. Box 117, 21000 Novi Sad, Serbia vericav@uns.ns.ac.yu

[2] University of Novi Sad, Faculty of Agriculture, Trg Dositeja Obradovica 8  P.O. Box 117, 21000 Novi Sad, Serbia

**Key words**
Herbicides, oak, microorganisms, forest soil

**Introduction**
Presence of weeds and great number of shrubby species  per area unit present the basic limiting factors for oak offspring development (Bobinac et al. 1991). Due to failure in seedling preservance, and quality offspring formation, as well as deterioration and slow development it becomes necessary to convey the control of weed vegetation in renovated penduculate oak forests. Herbicides are used to reduce weediness especially in the initial stages of oak development, when unfavorable influence of weeds on oak presents the greatest threat. From the total herbicide quantity applied both in agriculture and in forestry, the great part penetrates the soil, and significantly influences the activity of soil microorganisms. Microorganism can degrade herbicides and use them as the sources of biogenic elements for their physiological processes, or they can be toxic to microorganisms reducing their number and activity (Janjic et al. 1996, Regno et al. 1998). Considering the noxious effects of weeds on oak nursery plants, and the knowledge that microorganisms play big and indispensable role in providing the soil fertility, the aim of this paper was to study the herbicide selectivity in renovated penduculate oak forests, and the influence of applied herbicides on microbiological soil activity.

Materials and methods
Efficacy and selectivity of herbicides applied in renovated oak forests were tested during 2007 and 2008 in two localities differing in physicochemical soil properties. Trials were set up in a randomized block design with four replicates. The following herbicides were tested: (Mezzo 60-WG), tribenuron-methyl (Granstar 75-WG), nicosulfuron (Motivell), and clopyralid (Lontrel-100) applied postemergence. Herbicide efficacy was tested 15 and 30
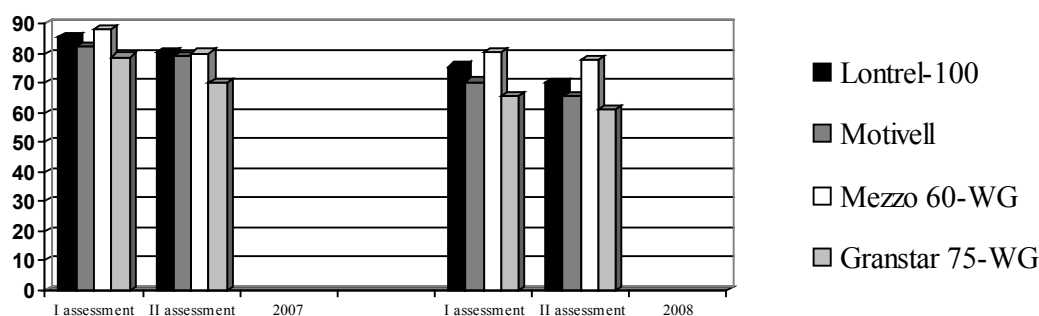


*Graph. 1 - Efficacy of tested herbicides in Naklo locality during 2007-2008*

days after herbicide application, and phytotoxicity was checked every 15 days from treatment to the end of vegetation. Soil for laboratory analyses was sampled at 7, 14 and 60 days after herbicides application. Total number of bacteria, participation of azotobacter, actynomycetes, fungi and aminoheterothrops was determined on appropriate nutritive media using method of dilution (Poshon and Tardieux 1962).

## Results and discussion

Investigation results revealed that there were some differences in efficacy and selectivity of tested herbicides. Application of herbicide metsulfuron-methyl (Mezzo 60-WG) provided the best efficacy of weed control in both localities. However, this herbicide and tribenuron-methyl (Granstar 75-WG) exerted phytotoxic effects on one-year and two-year old penduculate oak nursery plants. Height and diameter measurements at the end of vegetation period revealed that these two herbicides negatively influenced the growth of nursery plants. Herbicides clopyralid (Lontrel-100) and nicosulfuron (Motivell) were efficient in weed vegetation control, but revealed mild depressive effect on one-year, and two-year old oak nursery plants after application. Changes on leaves which appeared after application of clopyralid occurred in the form of spatulated leaf tips, and herbicide nicosulfuron caused mild leaf necrosis. One month after herbicide application changes on leaves disappeared, and plants developed with no visible changes. Herbicides clopyralid and nicosulfuron had no negative influence on growth of oak nursery plants.

Results obtained by studying microorganisms in soil after herbicide application showed that there was some influence of some herbicides on individual groups of microorganisms. Numerous investigations pointed out to the fact that there was no universal tendency in herbicide action in regard to soil microorganisms (Milosevic et al. 1995, 2001 Govedarica et al. 1995), and that intensity of the action depended on applied herbicide, type of microorganism, duration of herbicide action, as well as on physicochemical soil properties, climatic conditions, and some other factors. The strongest effects were usually exerted immediately after application, when their concentration in the soil was the greatest. Later microorganisms were also involved in degradation processes, herbicide concentration decreased, and their effects diminished (Radivojevic et al. 2004). Studied herbicides were shown to decrease the total number of bacteria in the soil in both localities across all sampling dates, and they also decreased the number of aminoheterothrops. Herbicide Lontrel-100 exerted inhibitory effects on azotobacter development, while sulfonylurea herbicides (Motivell, Mezzo 60-WG and Granstar 75-WG) exerted stimulative effects in both localities during studied years. Studying the effects of benzedin on pure azotobacter culture growth Pozo et al. (2000) also concluded that azotobacter was tolerant to toxic substrate material. Development of fungi and
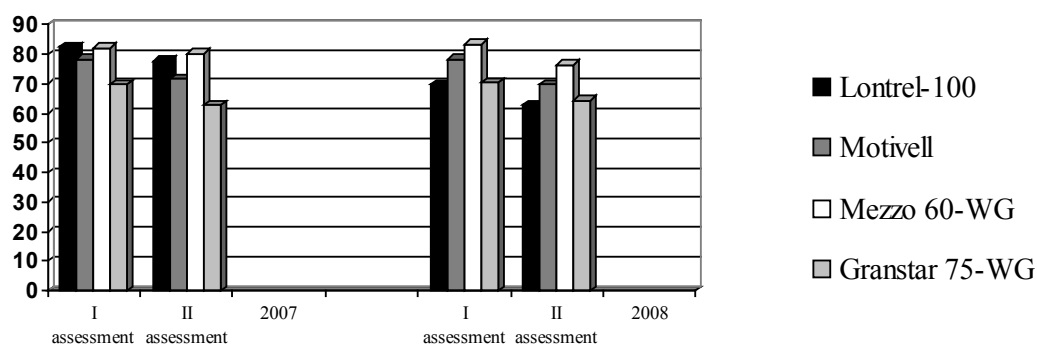


*Graph. 2 - Efficacy of tested herbicides in Varadin locality during 2007-2008*

actinomycetes was stimulated during entire testing period, which revealed that studied group of microorganisms were involved in herbicide degradation, and that they used their metabolites as energy source for their own physiological processes.

## Conclusions

There were some differences among tested herbicide in relation to efficacy and selectivity. Herbicides clopyralid (Lontrel-100) and nicosulfuron (Motivell) were efficient in control of weed population, and exerted no toxic effects on one, and two-year old oak nursery plants. They expressed mild depressive effects on oak nursery plants after application, but one month after herbicide application changes on leaves disappeared, and plants developed with no visible changes. Herbicide metsulfuron-methyl (Mezzo 60-WG) exerted high efficacy in weed control, but tribenuron-methyl (Granstar 75-WG) was phytotoxic to one- and two-year old penduculate oak nursery plants. Tested herbicides were shown to decrease the total number of bacteria and aminoheterothrops. The sulfonylurea herbicides exerted stimulative effects on azotobacter development, while effect of Lontrel-100 was inhibitory. Development of fungi and actinomycetes was stimulated during entire testing period.

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# Experience on mulching shade tree species in Italy

*F. Ferrini, A. Fini.*

Department of Horticulture - University of Florence
Viale delle Idee, 30 50019 Sesto Fiorentino (Florence)
francesco.ferrini@unifi.it
Tel. +390554574033 Fax +390554574017

A key to success for new tree planting both in open-field nursery and in the urban environment is the protection of young plants from non-crop plant species (including some hardwoods, shrubs, grasses, and forbs). These fast-growing plants often kill or greatly suppress desired trees by competing with them for light, water, and nutrients needed to grow. As a result, nurserymen, arborists and urban forester managers have used herbicides to suppress non-crop vegetation. However, in the present scenario, mulching can be an environmentally sound alternative to chemical to control undesired weeds.

Besides the effects on weed control, mulching can also influence tree growth physiology and soil characteristics in the medium-long term. Research on the development of non-chemical alternatives and better herbicide application technologies will therefore be central to this effort.

Based on this assumptions, starting from 2004 some research projects have been carried out in different parts of Italy, in different environments and on different species.

Results of these long-term projects have shown that mulching can have some positive effects on tree physiology, growth and on soil characteristics, though results can be variable according to the species. The presentation will summarize the results so far obtained from these projects.

# Grazing of livestock as control of herbaceous vegetation in coppice oak forests in Greece: trade-offs between herbs and oak sprouts in foraging decisions

*Thomas G. Papachristou[1], Panagiotis D. Platis[1]*

[1] Forest Research Institute, National Agricultural Research Foundation.
570 06 Vassilika, Thessaloniki, Greece
tpapachr@fri.gr

**Key words**
Deciduous oak forest, Quercus spp., management measures, Mediterranean basin

## Introduction

Oak forests cover a significant area (1,471,839 ha) in Greece but their production is limited to low economic value timber (Dafis 1966), as a result of human activities in the past, such as felling and grazing (Liacos 1980). These forests are state owned and the majority are intensively managed, with a clear cutting cycle ranging from 20 to 30 years. The clear cutting areas are protected for several years from domestic herbivores, depending on whether sheep (5 yr.), cattle (7 yr.) or goats (10 yr.) are involved. However, the absence of both overstory cover and grazing favour herbaceous vegetation and such stands carry high amounts of herbage (Papachristou et al. 2005), which may compete with developing oak sprouts. Moreover, these ecosystems are grazed within the vulnerable time and conflicts between forest authorities and animal herders are frequently present. Little information exists on how grazing animals select their diets in such ecosystems and whether this knowledge could be incorporated into vegetation management practices. The objective of the study reported here was to determine whether cattle and goats can control undesirable herbaceous vegetation in coppice oak forests after clear cutting without significant oak sprout damage (i.e. grazing and oak sprout growth are complementary), and how this might be affected by the time of applied grazing.

## Materials and methods

The study was conducted at Skepasto, Thessaloniki, in Northern Greece. The elevation of the study area is approximately 850 m and the annual precipitation is approximately 650 mm, with 80% falling between October and June. The mean annual temperatures range from 2.6 to 22.9 0C, with annual minimum and maximum temperatures ranging from -3.3 to 27.4 0C, respectively. The canopy vegetation was dominated by deciduous oaks such as Quercus frainetto Ten., Quercus petraea Liebl. and Quercus pubescens Willd., with other woody species including Carpinus sp., Fraxinus sp. and Quercus coccifera L.. There was also an undergrowth vegetation of forbs and grasses.

In April 1997, an experimental area of 45-ha was chosen, which consisted of three coppice oak plots (15-ha) that had been clear-cut in 1996 (CL1996), 1993 (CL1993), and 1990 (CL1990), and in which cattle and goats were grazing. In each forest stand, five 10 m x 10 m paired plots were chosen, which represented grazed and protected patches. The herbage biomass
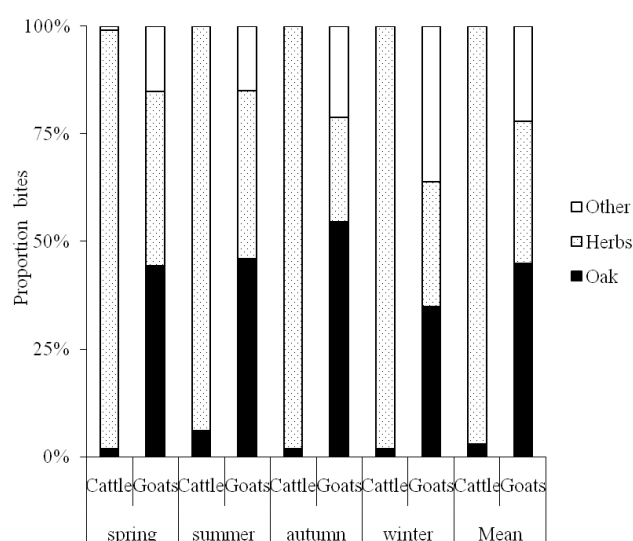
Fig. 1. Proportion of bites from vegetation categories (oak, herbs and woody species) by cattle and goats grazing on the studied coppice oak forest during the four seasons of the year in northern Greece.

within all plots was measured during the growing period, from May to November in 1998 and 1999. Behavioural observations on grazing animal species were conducted during the four seasons of the year and the proportion of each vegetation category (i.e. oak sprouts, other woody species and herbage) in animal total bites was calculated using the following formula: percent of bites on forage category (%) = bites per forage category / total bites x 100. In both protected and open plots the height of all oak sprouts on 5 preselected stumps was measured during the start of the experiment (April 1997) and at the end of each of the following five growing periods (end of November) from 1997 to 2001.

Data of oak sprout growth were subjected to analysis of variance and significant differences among means were detected at the 0.05 probability level, using the LSD test. The experimental design was a three factor randomized complete design with grazing as split plot in forest stands and years as split plots within grazing. When F-tests indicated significant differences, means were compared using LSD (P≤0.05).

**Results and discussion**
All forest stands carried similar amount of available herbage, which averaged over forest stands and growing season, 2580 kg/ha. Grazing animals removed throughout a growing period an amount of 1040 kg/ha. However, cattle took the vast majority of their bites on herbage (97%) while goat bites consisted of a mixture of oak browse (45%), herbaceous species (33%), and other woody species browse (22%) (Fig.1).

Height of sprouts were significantly (P<0.001) affected by grazing (Table 1). The fact that the three forest stands had similar sprout heights in the protected plots in 2001, suggests that long grazing applied on CL1990 (7 years after clear cutting) and CL1993 (4 years after clear cutting) affected the height of oak sprouts. A critical finding was that the absence of grazing for three years after the clear cutting (Table 1, protected plots of CL1996) ensured a height beyond the reach of goat ability to browse (1.5 m). This result may help managers create new grazing strategies that integrate goats in coppice oak forests.

*Table 1.  Mean height trends of sprouts in grazed (G) and protected (P) plots of the clear cut in 1990 (CL1990), in 1993 (CL1993) and in 1996 (CL1996) oak forest stands from November 1997 to November 2001 in northern Greece. Both grazed and protected plots up to the initiation of the experiment (April 2007) were grazed.*

| | CL1996 | | CL1993 | | CL1990 | |
|---|---|---|---|---|---|---|
| **Years** | **G** | **P** | **G** | **P** | **G** | **P** |
| Apr-1997 | 0.4 | 0.4 | 0.8 | 0.8 | 0.9 | 0.9 |
| Nov-1997 | 0.8 | 1.0 | 0.9 | 1.2 | 0.9 | 1.0 |
| Nov-1998 | 0.9 | 1.3 | 1.0 | 1.5 | 1.1 | 1.3 |
| Nov-1999 | 0.9 | 1.5 | 1.1 | 1.6 | 1.2 | 1.4 |
| Nov-2000 | 1.0 | 1.7 | 1.2 | 1.8 | 1.2 | 1.5 |
| Nov-2001 | 1.0 | 1.9 | 1.4 | 1.9 | 1.3 | 1.7 |

[1] CL1996: oak trees were felled in 1996; CL1993: oak trees were felled in 1993; CL1990: oak trees were felled in 1990.
[2] $LSD_{0.05}$ = 0.3 m to compare forest stands x grazing x years.

In conclusion, the applied grazing scheme reduced significantly the unwanted vegetation but it had an impact on oak sprouts. It seems that goats, who selected almost the half of their diets from oak sprouts, are responsible for the negative growth of sprouts.

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# Non-chemical forest vegetation management in Québec (Canada): a research perspective

*Nelson Thiffault*, Vincent Roy

Direction de la recherche forestière
Ministère des Ressources naturelles et de la Faune du Québec
2700, rue Einstein, Québec, QC. Canada, G1P 3W8
nelson.thiffault@mrnf.gouv.qc.ca

**Key words**
Integrated forest vegetation management, preventive silviculture, soil preparation, early planting, stock type, mechanical release

## Introduction

Vegetation management is crucial in meeting wood production objectives of plantations. As an example, Wagner et al. (2006) reviewed wood volume yield increases up to 477% for planted black spruce (*Picea mariana*) in eastern Canada following intensive chemical vegetation management, compared to untreated plots. In addition, releasing planted conifers from competition has the potential to balance the structural development of forest plantations (Jobidon 2000).

Although chemical vegetation management offers a great silvicultural potential to release conifer plantations (Dampier et al. 2006), and presents limited negative impacts on major biotic components (Lautenschlager and Sullivan 2002), public acceptability of chemical herbicides is low (Wagner et al. 1998). Moreover, worldwide certification systems generally discourage the use of chemical herbicides on certified land-base (e.g. Forest Stewardship Council 1996). In that perspective, chemical herbicides were banned on crown forest lands in Québec (~90% of the provincial forest land base) in 2001, a situation unique in Canada (Thompson and Pitt 2003). Our objectives are to briefly review the vegetation management strategy in Québec, with an emphasis being put on the main research that has supported its development. We also aim at identifying some challenges of vegetation management being faced in Québec in the context of implementing a zoning approach to intensive and ecosystem-based management.

## Historical context and the *Forest Protection Strategy*

Fortier et al. (2005) reviewed the historical context that has led to the adoption of a non-chemical vegetation management strategy in Québec. In summary, the early eighties were characterized by an ambitious reforestation program of 300 million seedlings•year$^{-1}$, which was concomitant with the development of glyphosate. However, the colossal reform of the Québec's forest regime of 1986 was rapidly followed by the development of a clear-cutting approach that protected advance-regeneration and soils (CPRS), and thus reduced the need for plantations. Following major public hearings, a provincial strategy was tabled in which the Government committed to eliminating the use of herbicides in the forest environment by 2001 (Ministère des Ressources naturelles du Québec 1994). Noteworthy, the adoption of the *Forest Protection Strategy* was followed by an official recognition of the environmental, social and economic roles of the forests; Sustainable Forest Management was included as a

preliminary provision of the Québec's Forest Act in 1996[1]. The *Forest Protection Strategy* triggered the development of preventive silvicultural strategies, along with alternative solutions to herbicides. CPRS systematically replaced all other clear-cutting methods, and reforestation was view thereon as a complement to natural regeneration when it does not supply an adequate number of quality seedlings within an acceptable time. In addition, mechanical release was identified as the principal method used to control vegetation.

**The role of research in the development of the strategy**

Table 1 lists a selection of studies conducted in Québec that have had a significant influence on the integrated vegetation management strategy, and are still influencing its application. For conciseness, selected studies were restricted to research papers published in peer-reviewed journals, and which dealt with conifers; studies on the reforestation of broadleaf species are also numerous (e.g. Cogliastro et al. 2006), and several peer-reviewed research notes played a significant role in the development of the strategy (e.g. Jobidon 1995).

Research has thus led to a vegetation management model adapted to the ecological characteristics of reforestation sites. This approach is first supported by preventive silviculture, which promotes advance-growth through careful logging, and reduces the need for artificial regeneration to less

*Table 1. Non-exhaustive list of studies conducted in Québec that have significantly influenced the provincial vegetation management strategy.*

| Reference | Main outcomes in regards of the provincial vegetation management strategy |
|---|---|
| (Jobidon 1992) | Development of an objective, operational method for assessing the need for release in conifer plantations |
| (Boily and Doucet 1993) (Pothier et al. 1995) (Ruel et al. 1995) (Paquin et al. 1999) (Ruel et al. 2000) (Laflèche et al. 2000) | Evaluation of advance-growth formed of seedlings and layers as a viable regeneration source, and of cutting with protection of advance-growth and soils as an efficient alternative to clear-cutting |
| (Jobidon 1993) (Jobidon 1997a) (Jobidon 1997b) | Understanding of competing vegetation responses to natural or silvicultural disturbances |
| (Jobidon 1994) | Determination of a critical light threshold for applying a release treatment in conifer plantations |
| (Jobidon and Charette 1997) | Refinement of the application of mechanical release treatments (number of treatments, time in the season) for various types of competing vegetation |
| (Jobidon et al. 1998) (Lamhamedi et al. 1998) | Identification of a target size for large containerized seedlings |
| (Jobidon et al. 1999) | Comparative assessment of mechanical and chemical release treatments effects on conifer growth on sites with moderate competition |
| (Lamhamedi et al. 2001) | Development and optimization of cultural techniques to produce large containerized conifer seedlings |
| (Greene et al. 2002) | Confirmation that reliance on advance regeneration or understory planting are the cheapest alternatives to achieve full or partial conifer stocking |
| (Thiffault et al. 2003) | Comparative assessment of large containerized and bare-root seedlings field performances, in the context of early planting (within a year following harvest) to provide a competitive advantage to the planted seedlings |
| (Jobidon et al. 2003) | Evaluation of the competitive potential of large containerized seedlings in high-competition environments, and their responsiveness to mechanical release |
| (Thiffault et al. 2004) (Thiffault et al. 2005) (Thiffault and Jobidon 2006) | Development of mechanical silvicultural options for reforestation of boreal sites invaded by ericaceous species |
| (Jobidon et al. 2004) (Cyr and Thiffault 2009) | Assessment of the mid- and long-term impacts of mechanical release and cleaning on floristic diversity and stand productivity in conifer plantations |
| (LeBel and Dubeau 2007) (Toupin et al. 2007) | Models of workers productivity in mechanical release treatment and pre-commercial thinning operations |

1 Forest Act, R.S.Q., chapter F-4.1.

than 20% of the area logged annually. It then includes the use and harmonization of site preparation operations, early planting, use of large seedlings stock and mechanical release.

## Challenges in the context of intensive and ecosystem-based management

In 2008, the Québec Government committed to implementing ecosystem-based management on ~70% of its public forests, dedicating a significant land-base to intensive silviculture, while maintaining its objective of protecting 8% of its territory. The non-chemical forest vegetation management strategy is well-adapted to attain the biodiversity objectives of ecosystem-based management (Hartley 2002). However, research demonstrates that on some sites, mechanical release alone does not promote optimal crop-tree growth, owing to the rapid resprouting of competitors (e.g. Jobidon 1997a, b) and the competition by herbaceous species (Pitt et al. 2009). Such losses in wood productivity may be an issue in intensive silviculture scenarios. Research must continue to further fine-tune the silvicultural strategies to manage plantations of high expected-yields. Such research should also consider plantation effects on biodiversity at the stand and landscape levels (Jobidon et al. 2004). Globally, the greatest challenge remains to globally assess, from an environmental, social, and economic perspective, the sustainability of the selected strategies (Fortier and Messier 2006).

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# Effects of different treatments on *Sorbus aucuparia* and *Populus tremula* sprouting in mesic forests in Finland

*Leena Hamberg, Irja Löfström, Minna Malmivaara-Lämsä, Henna Vartiamäki, Sauli Valkonen, Jarkko Hantula*

Finnish Forest Research Institute
P.O. Box 18 (Jokiniemenkuja 1)
FI-01301, Vantaa
Finland
leena.hamberg@metla.fi

**Key words**

Saplings, *Chondrostereum purpureum*, regeneration areas

## Introduction

Rowan (*Sorbus aucuparia*) thickets are abundant in urban forests in Finland restricting the regeneration and growth of other tree species (cf. Lehvävirta and Rita 2002). Rowan, but also aspen (*Populus tremula*) may thrive because large herbivores are mainly absent in urban forests (Andrén and Angelstam 1993). However, especially aspen can be abundant also in rural areas.

Mechanical cutting at 10-15 cm above the ground level is a traditional and commonly used method to prevent excessive growth of thickets. However, this may not be the most efficient treatment, because usually the broadleaves sprout vigorously after cutting (see e.g., Mulak et al. 2006). Therefore, mechanical cutting must usually be repeated within a couple of years to be effective, which causes considerable costs. The use of chemical herbicides might be an efficient way to prevent sprouting, but it is not permitted in urban areas. Chemical herbicides are not much used in commercial forestry either, because of their harmful impacts on the environment (Metsäsertifioinnin…2005). Therefore, new alternative methods are needed.

We compared different mechanical and biological treatments to determine the best way to restrict the excessive growth of rowan and aspen saplings in regeneration areas of spruce (*Picea abies*).

## Materials and methods

Ten mesic sites were chosen for the study in Helsinki, Sipoo and Lapinjärvi, southern Finland. All sites included spruce saplings with rowan-aspen thickets. We compared three different treatments for rowan and aspen: 1) traditional method: removal of saplings by cutting them 10-15 cm above the ground level, 2) moose simulation: removal of saplings by cutting them 1 m above the ground level (the height where moose browse saplings) and 3) biological control: removal of saplings as in alternative 1 and covering the entire surface of freshly cut stumps with the mycelium of *Chondrostereum purpureum*, a biological control agent, which is under development in Finland.

Five sample plots for each treatment were established in 2007. The total number of saplings investigated per treatment was 80-90, i.e. altogether 272 rowan and 258 aspen saplings. The

size of studied saplings was measured (diameter 10 cm above ground level) and the number of other saplings and the volume of retained large trees were calculated around each sapling before the treatments were implemented, because intertree competition may affect sprouting (cf. Valkonen et al. 2002, Mulak et al. 2006).

Sample plots were treated in June 2007. Field measurements were performed in September 2007 and 2008 to study the effects of different treatments on rowan and aspen sprouting. The number and height of new stump and root suckers per stump (i.e. per sapling) were used to indicate the effectiveness of the treatments.

Generalized linear mixed models (GLMMs) were used to analyse the data. The diameter of a sapling, the number of saplings and volume of retention trees around each sapling were taken into account when models were run.

### Results and discussion

Our results revealed that the growth of new sprouts was slowest when *C. purpureum* was used as a biological control agent (treatment 3). The number and height of rowan stump suckers were lower in biocontrol than in other treatments. However, the number of root suckers was higher after biocontrol treatment than after other methods, but the height of root suckers did not differ between the treatments. Results concerning aspen were not as clear as for rowan, but the trend was similar: biocontrol treatment was more effective than the other treatments.

Although biocontrol treatment seems to be the most efficient way to prevent sprouting of rowan and aspen, it cannot be used commonly. Method is under development for commercial use in Finland, but development work and registration process may take several years. In Canada, registered *C. purpureum* products for biocontrol purposes are available, but the use of those products in Finland is questionable, because of uncertainty about their action in a different environment. At present, using *C. purpureum* as a biocontrol agent in Finland is only allowed for research purposes. It should not be used within 500 m from gardens, because the fungus can infect freshly pruned fruit trees (De Jong 1990). However, *C. purpureum* is very common, abundant indigenous fungus in Finland (Kauppila and Niemelä 1986). *C. purpureum* infects only damaged broad-leaved trees, and for healthy broad-leaved trees and conifers it is not hazardous (Wall 1991). Biocontrol treatment with *C. purpureum* may be a future solution for the rowan problem in urban forests, which are not close to gardens and may help in restricting the excessive growth of aspen thickets in urban and commercial forests.

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# Afforestation with beach and oak on heavy soils – mortality and growth as affected by vegetation management strategies

*Niclas S. Bentsen[1], Frans Theilby[1], Thomas Kudal[1]*

[1] University of Copenhagen
Centre for Forest, Landscape and Planning
Vedelsgade 6, DK-7100 Vejle
Denmark
nb@life.ku.dk

**Key words**
Soil preparation, management strategies, pre-treatment, weed control

## 1. Background
In 1989 the Danish government decided to double the Danish forest area within a period of 80-100 years. The idea was to convert marginal agricultural lands, mostly on lighter soils, into forest. Since then focus has shifted and afforestation is now perceived as a means of supporting e.g. ground water protection, carbon sequestration and public recreation. As a consequence of this shift afforestation today takes place on a wider range of soil types, and experience on soil preparation and vegetation management gained during many years of converting poorer agricultural soils into forest proved inadequate for afforestation on heavy and fertile agricultural soils.

## 2. Methods
8 field experiments were established in 1998/99 with the purpose of examining the efficacy of different vegetation management strategies. 4 experiments had specific focus on different soil preparation methods and the other 4 focused on vegetation control methods. During inventory 6 years after planting one of the vegetation control experiments had to be excluded as it was more or less destroyed by the mechanical vegetation control.

*2.1 Treatments*
The treatments applied in the experiments are shown in table 1.

Table 1. Experimental treatments applied in the experiments. All combinations of pre-treatment, soil preparation and vegetation control within each theme were examined.

| Factor | No. of localities ($\tau$) | No. of replicates ($\beta$) | No. of treatments | Pre-treatment ($\gamma$) | Soil preparation ($\theta$) | Vegetation control ($\delta$) |
|---|---|---|---|---|---|---|
| Theme | | | | | | |
| Soil preparation | 4 | 4 | 16 | -None <br>-Spraying | -None <br>-Trad. ploughing <br>-Strip cultivation <br>-Deep ploughing | -None <br>-Spraying |
| Vegetation control | 3 | 4 | 10 | -None <br>-Spraying | -Trad. ploughing | -None <br>-Uni-directional cultivation <br>-Bi-directional cultivation <br>-Trampling <br>-Spraying |

## 2.2 Experimental design

The experiments focused on the effect of soil preparation methods were established as factorial triple-split plot design with pre-treatment as whole-plot factor, soil preparation as sub-plot factor and vegetation control method as sub-sub-plot factor. The statistical model for analysing the results is shown below.

$$Y_{ijklm} = m + t_i + b_{j(i)} + g_k + (bg)_{j(i)k} + q_l + (bq)_{j(i)l} + d_m + (bgd)_{j(i)km} + (gq)_{kl} + (gd)_{km} + (qd)_{lm} + (gqd)_{klm} + e_{ij(i)klm}$$

The experiments focusing on vegetation control methods were simpler, using a factorial split-split plot design, with pre-treatment as whole-plot factor and vegetation control method as sub-plot factor. These experiments were analysed with the following model.

$$Y_{ijkl} = m + t_i + b_{j(i)} + g_k + (bg)_{j(i)k} + d_l + (bd)_{j(i)l} + (gd)_{kl} + e_{ij(i)kl}$$

## 3. Results

### 3.1 Soil preparation experiments

Considering the general effects across localities we found in the soil preparation experiments **in beech** a significant effect on seedling mortality of the choice of soil preparation method. There was no effect of pre-treatment or vegetation control. On average deep ploughing and strip cultivation resulted in mortality rates of 22 % and 25 % respectively. No soil preparations lead to an average mortality of 35 %. Traditional ploughing was placed in between with a mortality rate of 29 % (fig. 1).

**In oak** we found no effect on mortality of neither pre-treatment, soil preparation or vegetation control.

Growth rates were also affected by soil preparation. In **Oak** we found that deep ploughing had resulted in the lowest height after 6 years. This is in contrast to the results for **beech**, where deep ploughing and traditional ploughing lead to the highest trees after 6 years.

### 3.2 Vegetation control experiments

In the vegetation control experiments we found across localities no effect on seedling mortality of neither pre-treatment or vegetation control method. This counts for both **beech and oak**. **In oak but not in beech** height growth was affected by vegetation control. Spraying
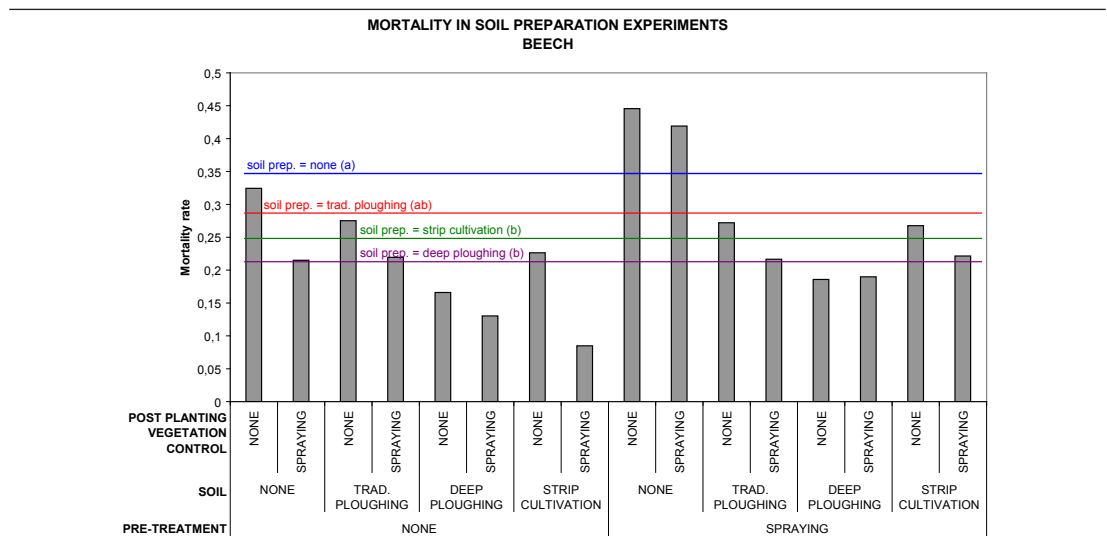


Figure 1. Seedling mortality of beech in soil preparation experiments. Horizontal lines show the general effect of soil preparation methods across pre-treatment and vegetation control treatments. Treatments followed by the same letter in brackets are not different (ὰ=0.05).

with glyphosate lead to an average height after 6 years of 275 cm, which was significantly higher than treatments with no vegetation control or cultivation as control method (236 - 243 cm). Trampling was placed in-between with 256 cm (fig. 2).

## 4. Discussion and conclusion

Already in the planning phase of an afforestation project a proper choice of vegetation management strategy becomes evident. Factors like row spacing, row direction subject to topography and distance between tracks may greatly affect the applicability of a chosen strategy.

A vegetation management strategy is a number of subsequent actions starting with initial pre-treatment over soil preparation to vegetation control several years after planting. Preferably one step in the strategy should be beneficial to the next.
Due to the experimental design individual strategies are represented by the interaction of pre-treatment, soil preparation and vegetation control. Across localities we saw only few significant interactions and no unambiguous patterns were found. However on individual localities we found differences. In one locality especially mortality of **beech** decreased with intensification in the two last steps of the applied vegetation management strategies i.e. soil preparation and vegetation control.

In **beech** mice can be detrimental to seedling survival. A side effect of both soil preparation and vegetation control was found, where an increase in the area prepared reduces the damages caused by mice. Ploughing is better than strip cultivation, which again is better than no preparation. As for vegetation control we found that spraying reduces mice damages as compared to no vegetation control.

Deep ploughing affects beech and oak differently. **Beech** responded positively to deep ploughing both in survival and growth, whereas **oak** grew poorer on deep ploughed soil. We have no logical explanation for that.

An important lesson learned from these experiments is that the difficulties in carrying out mechanical vegetation control in practice must not be under estimated. We lost an experiment because the tractor driver couldn't see the seedlings in the high vegetation, and thus couldn't navigate accurately.

**HEIGHT IN VEGETATION CONTROL METHOD EXPERIMENTS**
**OAK**
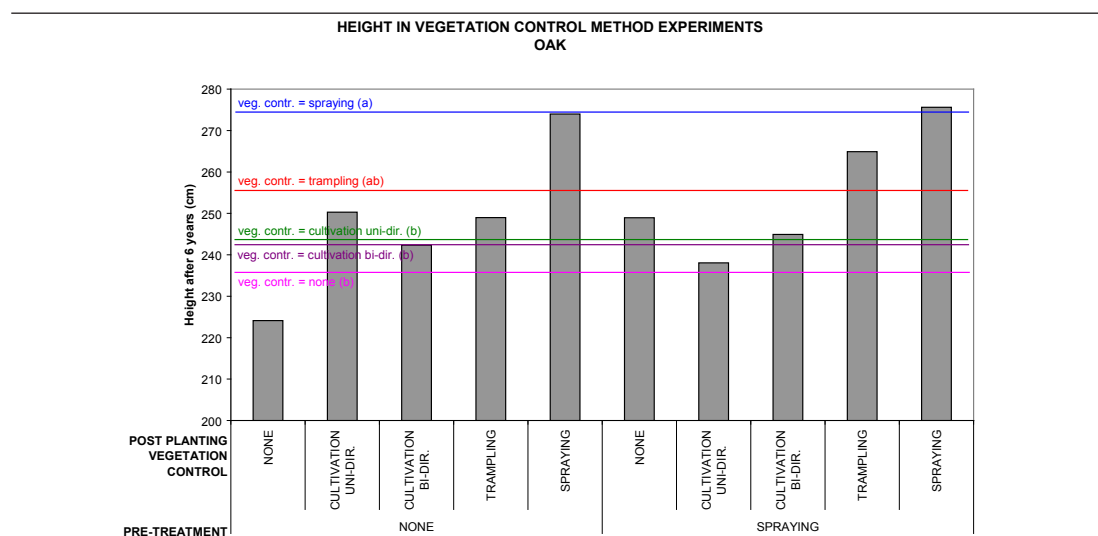


Figure 2. Height of oak 6 years after planting in experiments on vegetation control methods. Horizontal lines show the general effect of vegetation control methods across pre-treatment. Treatments followed by the same letter in brackets are not different (ȧ=0.05).

# Vegetation Management to Optimize Carbon Assimilation and Ameliorate Climate Change – Canada's Long-term Soil Productivity (LTSP) Project

*Phillip E. Reynolds[1], Gordon Brand[1], Tom Weldon[1] and Neil Foster[1] (deceased)*

[1] Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre
1219 Queen Street East
Sault Ste. Marie, Ontario
Canada P6A 2E5
preynold@nrcan.gc.ca

**Key words**
Carbon assimilation, harvesting, site preparation, soil compaction, nutrient removals, soil productivity

## Introduction

The Ontario Long-Term Soil Productivity (LTSP) Study was established in 1993 (Tenhagen et al., 1991) to examine the effects of harvesting and other site preparation techniques, inclusive of vegetation management, on long-term productivity (i.e, yield, biomass, Carbon sequestration) of either jack pine or black spruce plantations. This study reports on six replicated 10-year old jack pine plantations located within north-central Ontario. Original jack pine plantations were harvested [full-tree (FT) or tree-length (TL)], mechanically site prepared by various techniques [disc-trenching, blading (B) to remove topsoil (windrows), or no site preparation (SIP)]. Additionally, other plots were compacted (C) to simulate the effects of heavy equipment operations during harvesting or mechanical site preparation. Treatment plots were then planted and then sub-divided into herbicide or non-herbicide sub-plots. The overall hypothesis of the LTSP study, a component of the larger North American LTSP study, being directed by the U.S. Forest Service, is that soil compaction or nutrient removals seriously impact future stand productivity, and presumably Carbon sequestration (Powers and Van Cleve, 1991). Objectives of this study were to 1) quantify jack pine gas exchange differences among treatments or sub-treatments for 10-year old plantations and 2) to ascertain if treatment differences affect Carbon assimilation on a stand or landscape scale.

## Materials and methods

For the present study, basic small plot treatments consisted of tree-length harvested with no SIP (controls), FT or TL harvested followed by standard disc-trenching, full-tree harvested followed by blading (B), and full-tree harvested followed by blading and then soil compaction (C). All plots were post-harvest planted. Additionally, each of the plots was divided into sub-plots either herbicide released annually to control weeds or no herbicide release.

To assess treatment differences, gas exchange [stomatal conductance $(G_s)$, transpiration (E), net assimilation (NA), and environmental parameters (temperature, humidity, $CO_2$ concentrations)] were measured in May and August at all six locations using a Li-Cor 6200 Photosynthesis System, along with soil moisture and plant water potential. Additionally, plot leaf areas were determined using a Li-Cor LAI-2000. Using measured gas exchange parameters, water use efficiencies were calculated as actual, AWUE = NA/E or as intrinsic, IWUE =

NA/$G_s$ (Larcher, 1980; Farquar and Richards, 1984). Mesophyll conductance ($G_m$ = NA/mesophyll $CO_2$) was also examined (Leverenz, 1981).

## Results and discussion

For both measurement times, consistent treatment differences were observed at several locations. These consisted of the following: 1) stomatal conductance and transpiration were higher for compacted and bladed plots than for other treatments, with no SIP plots generally being intermediate, and full-tree and tree-length plots being lowest; 2) concurrently, both actual and intrinsic water use efficiencies were higher for FT and TL plots than for other treatments, with no SIP plots remaining intermediate, and C and B plots being lowest; and 3) basic rates of NA did not tend to differ among treatments.
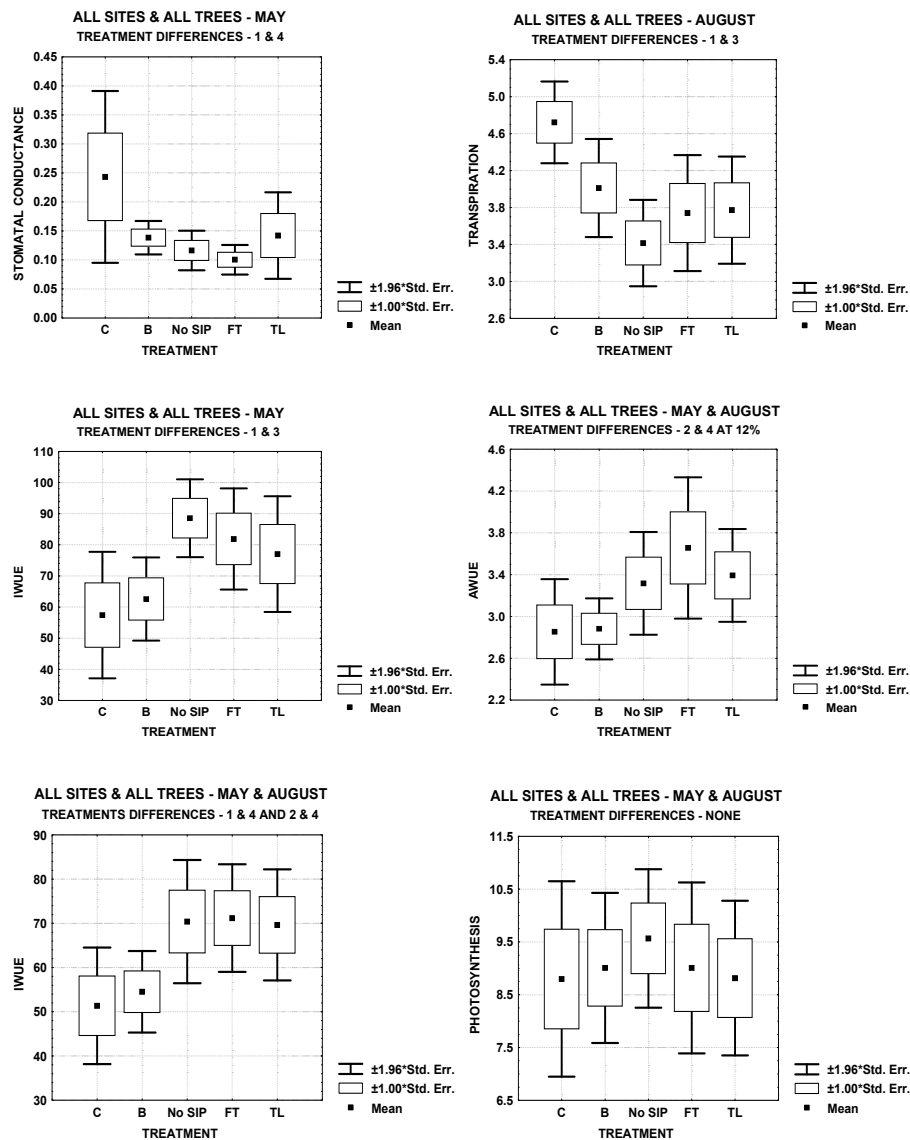
When herbicide effects were assessed, only transpiration differed significantly. Additionally, the foliage of trees in C and B plots was less vigorous (less leaf area) than those in FT or TL plots, and morphological appearance differences for trees were evident for the differing treatments. These foliage differences were paralleled by measurable differences in plot leaf areas as determined by the LAI-2000. Measured leaf area index (LAI) for the various treatments was a very good surrogate for mean needle leaf areas.
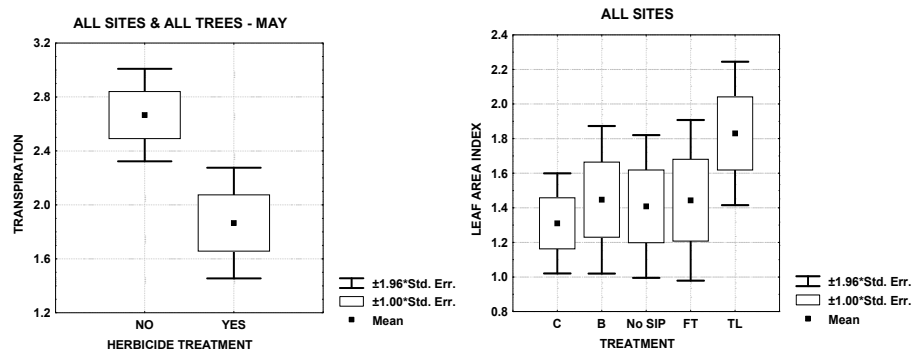


These leaf area differences for differing treatments, coupled with similar NA rates for all treatments, equate to differing amounts of Carbon assimilation on a stand basis, depending upon prior operational treatments, and also translate to landscape differences in Carbon assimilation dependent upon prior harvesting or stand site preparation techniques used. We therefore predict that FT or TL harvesting, followed by disc-trench mechanical site preparation, with avoidance of blading, and attempts to minimize soil compaction, will all lead to substantially greater Carbon assimilation by these intensively managed plantations. We also would hypothesize that higher transpiration and stomatal conductance in compacted and bladed plots, where trees have less foliage area than in FT or TL plots, is a likely plant compensation mechanism, allowing trees to have comparable Carbon fixation rates regardless of treatment. Even so, even with comparable C fixation rates, actual Carbon assimilation rates on a stand or landscape scale can still be expected to differ significantly, and do, dependent upon measured leaf areas associated with these stands.

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# How best should we manage hybrid poplar plantations?
# Interactions of site preparation, vegetation control and fertilization

*Simon Bilodeau-Gauthier[1], David Paré[2], and Christian Messier[1]*

[1] University of Quebec in Montreal, Centre for Forest Research, Montreal (QC), Canada.
[2] Laurentian Forestry Centre, Canadian Forest Service, Natural Resources Canada, Quebec City (QC), Canada. Corresponding address: Simon Bilodeau-Gauthier, Institut des sciences de l'environnement, Université du Québec à Montréal, C.P. 8888, Succursale Centre-Ville, Montreal (QC), H3C 3P8, Canada. simonbgauthier@yahoo.ca

**Key words**
Hybrid poplar, silviculture, site preparation, plant competition, fertilization.

## Introduction

The silviculture of hybrid poplars is a promising solution to reduce the pressure on natural forests while maintaining the wood supply to industries. However, hybrid poplars are sensitive to competing vegetation and to inadequate soil conditions and fertility. Possible management tools include mechanical soil preparation (MSP), vegetation control (VC), and fertilization. Apart from clone selection tests, there are no hybrid poplar plantations more than a few years-old in the soils and climate of the region of this study. It is thus imperative to develop suitable methods in order to assess the required soil and environmental conditions that will ensure the success of those plantations.

## Methods

Eight formerly forested sites (total 40 ha) were chosen in the Saguenay-Lac-St-Jean region (southern boreal forest) of the province of Quebec, Canada. Hybrid poplar seedlings of the clone *Populus maximowiczii* x *Populus balsamifera* were planted in the spring 2004. Five MSP
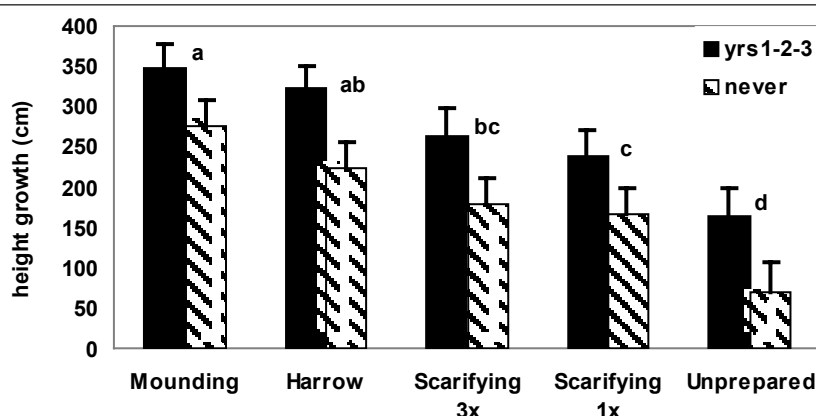


Figure 1. Effect of mechanical soil preparation (MSP) and vegetation control (VC) on height growth (sum of five years, 2004-2008) of hybrid poplars, across five different MSP treatments. Only the two extreme VC treatments are shown, the most (at yrs 1, 2, and 3) and the least (never) frequent. Values are means of trees from 8 blocks, error bars are SE. Between MSP treatments, different letters represent significantly different means at α = 0.05. The two VC treatments are significantly different at α = 0.05 within every MSP treatment.
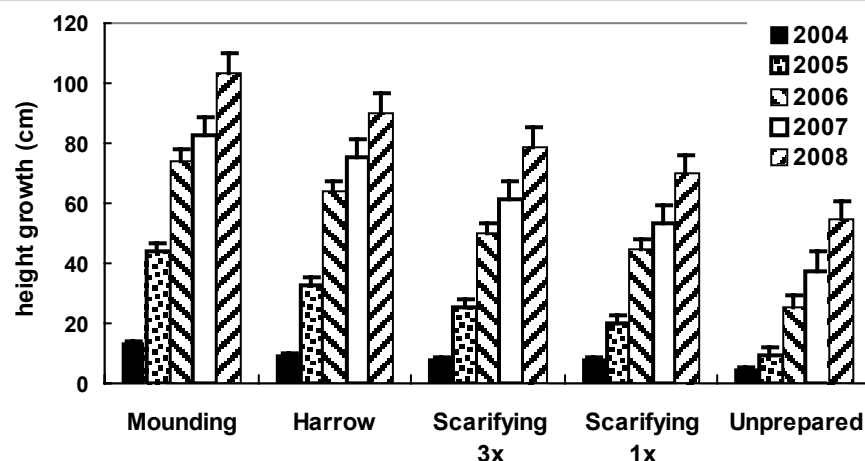
*Figure 2. Annual height growths (2004 to 2008) of hybrid poplars across five different mechanical soil preparation (MSP) treatments. Values are means of trees from 8 blocks, error bars are SE.*

techniques were tested: mounding, harrowing, scarifying once (one run of the machinery; 1x), scarifying thrice (three runs; 3x), as well as no preparation. The four VC treatments corresponded to four different frequencies: *i*) never, *ii*) at year 2, *iii*) at years 1 and 3, and *iv*) at years 1, 2, and 3 (where the year of planting is considered as year 0). In July 2008, two doses (0 – a control –, and 400 g tree$^{-1}$) of fertilizer, as well as two assortments of nutrients (N only, as 18-0-0; and N+P, as 18-46-0) were applied at the base of selected trees in the VC subplot *iii* of three MSP treatments (unprepared, harrow, and mounding) and across all eight blocks.

### Results

Height growth over 5 yrs was enhanced by mechanical soil preparation (MSP) done prior to planting. There is a significant (at $\alpha = 0.05$) gradient between the different MSP treatments (Fig. 2), where the best growths are obtained in the order: mounding > harrowing > scarifying (3x) > scarifying (1x) > no preparation (control). Removal of above-ground parts of competing herbaceous and woody vegetation also increased height growth of trees (Fig. 1). The different frequencies of vegetation control effected growth in the order: at years 1, 2, and 3 > at year 2 > at years 1 and 3 > never. The gradient of the effect of MSP on growth is similarly observed on annual height growths (Fig. 2), although in early years the difference was most evident when comparing the two extreme treatments (mounding *vs* control/unprepared), while intermediate treatments were relatively similar and only differentiated later on. There was no significant difference between fertilizing with N only compared to combining N+P (data not shown). Still, fertilized trees grew higher than unfertilized trees during the year of fertilizer application, yet only in the mounding treatment was it significant (Table 1).

*Table 1. Effect of fertilization (N and N+P combined) on annual height growth (2008) of hybrid poplars, in three mechanical soil preparation (MSP) treatments. Probability that the growth of fertilized trees is higher than that of unfertilized trees is the result of an analysis of variance conducted separately for each MSP treatment (n = 8).*

| MSP treatment | Height growth in 2008 ± SE (cm) | | Improvement from fertilization | | Prob [Fert > Non-Fert] |
|---|---|---|---|---|---|
| | Fertilized | Unfertilized | % | cm | |
| Mounding | 136.8 ± 10.5 | 104.1 ± 9.1 | 31.3 | 32.6 | 0.00935 |
| Harrow | 106.1 ± 11.8 | 92.4 ± 12.4 | 14.7 | 13.6 | 0.468 |
| Unprepared | 67.2 ± 15.9 | 58.4 ± 16.4 | 15.1 | 8.8 | 0.681 |

## Discussion

The gradient of increasing height growth across MSP treatments parallels the gradient of increasing MSP intensity: the slowest growths are obtained in unprepared soils that retain the original soil layering patterns (a relatively thick overlying organic horizon), whereas the best growths are found among the strongly disturbed mounds mostly made up of mineral soil, and intermediate growths are produced by varying intensities of organic and mineral soil mixing (harrowing and scarifying). The effect of competition control is more evident on the more productive sites (data not shown) and in the less severe preparation treatments (mean growth of trees in vegetation-controlled plots of unprepared sites is around twice that of trees in no vegetation-controlled plots, see Fig. 1). Actually, it has been suggested that MSP in itself can already be a way of limiting competing vegetation (Pehl and Bailey 1983, Ross and Walstad 1986). Fertilization, on the other hand, can provide substantial improvement in immediate growth, although it does not seem to compensate for inadequate soil preparation since only on mounds was this improvement significant. This could be explained by a more important root development in early years, revealed by comparative excavations of roots between mounds and unprepared plots (data not shown). Furthermore, the underlying – and undisturbed – organic horizon over which the mound was formed might represent a reservoir of nutrients available to the tree once its roots can reach deep enough. This potential reservoir is also relatively devoid of competing roots from other plants. As a matter of fact, in unprepared plots, hybrid poplar roots avoided the nutrient-rich organic horizon where competition was high, whereas in mounds proportionally more fine roots were produced in the underlying organic horizon.

## Conclusion

Results of this study have important implications for the future management strategies of hybrid poplar plantations in formerly forested sites. The different techniques and management tools used here have proven to interact according to site conditions, either intrinsic or created, in ways that can influence the choice of using those techniques. Still, other considerations (e.g., socio-economical) might further influence the decision process.

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# Changes in management of undesirable forest vegetation in Czechia during two decades

*Petr Zahradník[1], Viktor Janauer[2] & Pavel Cudlín[3]*

[1] Forestry and Game Management Research Institute, Strnady 136, CZ-252 02 Jiloviste, Czech Republic; zahradnik@vulhm.cz; +420 257 921 286; GSM +420 602 208 802; fax +420 257 921 444 (corresponding author)
[2] L.E.S.CR s.r.o., Strnady 136, CZ-252 02 Jiloviste, Czech Republic; janauer@lescr.cz; +420 257 922 638
[3] Institute of Systems Biology and Ecology, Academy of Sciences of the Czech Republic, Na Sadkach 7, 370 05 Ceske Budejovice, Czech Republic; pavelcu@usbe.cas.cz; +420 604 272 215

During the last two decades basic changes of weed management have come about in forestry. Before "the velvet revolution" in 1989, the herbicide usage was the most important method in weed management . It was a standard that more than 90 % of applications was carried out by herbicides. At the beginning of 90th of the last century the herbicides with effective substance hexazinone (common name of Velpar) were commonly used herbicides and the herbicides on the basic of glyphosate started to be known. Simultaneously the application of graminicide for retarding of annual weeds species has spread. At the beginning of new millennium we used herbicides in total value of almost 90 milions CZK; during last five years the consumption has reduced from ecological and economic reasons to approximately 40 milions CZK . The specific problem of our country is an intensive application of herbicides in weed management in forest nurseries, which are situated on forest land.

# Biological Control of Invasive Weeds – A Tool for Integrated Vegetation Management

*Marion K. Seier*

CABI Europe-UK, Bakeham Lane, Egham, Surrey, TW 20 9TY, UK, m.seier@cabi.org

Invasive plant species have been reported to affect almost every ecosystem around the globe and their devastating impacts on native biodiversity, local economies as well as human and/or animal health have been well documented over the years (Pimentel 2009; Reinhardt et al. 2003). In forestry, exotic and native weeds compete with upcoming seedlings and young trees for light, water and nutrients and, thus, directly affect tree growth in commercial plantations as well as natural regeneration in native woodlands. The increased awareness of invasive species issues in Europe during recent years has also led to the search for suitable mangement strategies for the most aggressive invaders. Traditionally, control methods for invasive weeds have strongly relied on mechanical, cultural and chemical means. However, these methods are costly and labour intensive, and have often proven not to give sufficient control (Green 2003). Furthermore, growing environmental awareness is calling for a reduction in pesticide use. The actual or pending withdrawal of selected herbicides from the market or restrictions for their use, i.e. in amenity areas, riparian habitats and forestry, have re-enforced the need to consider additional environmentally-friendly methods for weed management. Biological control, defined as "the use of living organisms to control pest species" (Waage and Greathead 1988; Watson 1991) offers such an alternative, environmentally-benign and cost-effective option for weed control. This method has long been used as part of an integrated weed management strategy in countries such as Australia, New Zealand, South Africa and the USA (McFadyen 1998).

Biological control is traditionally divided into two approaches: classical or inoculative biological control (CBC) and inundative biological control. CBC is most suited to target alien invasive plant species which have arrived in new environments or habitats without their associated suite of specialised natural enemies, which limits their spread in their native ranges. The aim of CBC is to introduce host-specific, co-evolved invertebrates and/or pathogens, from the centre of origin of the target weed, into its new invasive range in order to redress this imbalance. Successful CBC will not eradicate the alien weed but rather suppress its population to a level where the plant species poses no ecological or economic threat. The earliest successful example of CBC is the control of prickly pear (*Opuntia stricta*) in Australia with the pyralid moth *Cactoblastis cactorum* in the 1920s (Dodd 1959). The more recent example of the rust *Maravalia cryptostegiae,* used against Madagascan rubbervine (*Cryptostegia grandiflora*) invading native Eucalypt forests in Australia, illustrates the success of a fungal pathogen as a biocontrol agent (Tomley and Evans 2004). In the case of invasive, but commercially important Australian *Acacia* spp. in South Africa, CBC has been applied to restrict the spread of these species by using host-specific, seed-feeding beetles from Australia, rather than causing mortality of whole trees (Neser and Kluge 1986).

The inundative approach exploits indigenous natural enemies; i.e. those that are already present in the environment where a plant species poses a weed problem, but do not control the plant population. Since fungal pathogens are predominantly used for this method, it is often better known as the mycoherbicide approach. This strategy is based on the mass production and formulation of a selected agent. This product is then applied, at a critical growth stage of the weed, similar to the application of a chemical herbicide. Due to the cost generally involved with production, registration and marketing of a mycoherbicide, this approach is most suited to commercially important weeds i.e. in high value agriculture. Site-selective stump treatment is another approach encompassed in this concept and has been employed in forest ecosystems. This method of applying mycoherbicides based on indigenous wood-rooting fungi is used to prevent the re-sprouting of woody invasives and has been successfully employed using *Cylindrobasidium laeve* against exotic *Acacia* species in South Africa (Lennox et al. 2000). In the Netherlands the fungal pathogen *Chondrostereum purpureum* has been used as a cut-stump treatment against North American *Prunus* spp. and *Populus* spp. (de Jong 2000) and in Canada against broadleaf forest tree species (Wall 1990).

In Europe the uptake of biological control as a strategy for weed management has been relatively slow; however, a number of research programmes are currently underway with some of these close to implementation. In the UK a long-running biocontrol initiative against Japanese Knotweed (*Fallopia japonica*), widely regarded as the most serious weed in Europe, has evaluated two promising biocontrol agents from Japan: the psyllid *Aphalara itadori* and the leaf-spot fungus *Mycosphaerella polygoni-cuspidati*. With respect to the psyllid, the documentation required by the UK government to consider the release of this agent has been submitted to the relevant regulatory authorities, and a decision is pending (Djeddour et al. 2008; Shaw et al. 2009). A recently commenced biocontrol programme against the riparian weed Himalayan balsam (*Impatiens glandulifera*) has identified several promising natural enemies during survey work undertaken in the Himalayan native range of the weed. These agents are currently being assessed as potential biocontrol agents (Tanner 2008). In Finland the wood-rooting pathogen *Chondrostereum purpureum* is under evaluation as a cut-stump application for control of re-sprouting of birch (Vartiamäki et al. 2008). The same fungal pathogen will also be assessed for its potential to control *Rhododendron ponticum* in Ireland.

Biological control can constitute a valuable tool for economic and sustainable vegetation management in forestry and has as such already been successfully implemented in countries such as Canada, Australia and South Africa. However, the choice of a suitable target species, as well as of the appropriate approach, is critical for a successful biological control programme. In her review, Green (2003) has identified potential target weeds for biocontrol in forestry in the UK. Control agents for two of these species, Japanese Knotweed and *Rhododendron ponticum*, are already under investigation in the UK and Ireland, respectively. Should these agents successfully contribute to the sustainable control of these weeds the way for future biological control programmes in Europe will be paved.

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# Effects of different weed control methods on flora and fauna

*Hans Peter Ravn* & *Torben Riis-Nielsen*

Forest & Landscape, University of Copenhagen, Hoersholm Kongevej 11, 2970 Hørsholm, Denmark.
hpr@life.ku.dk; trni@life.ku.dk phone: +45 35 33 15 00, fax: + 45 35 33 15 17

In two studies the differences in flora and fauna was studied in areas that have been subject to different methods or intensities of weed control.

The first study was carried out in two types of forest areas: A six year old, 3rd generation Christmas tree plantation in an old forest area and in a new established forestation area. The weed treatments involved were chemical control, mechanical control of different intensities (sub soiling, rotary cultivator, rotary harrow, scythe cutting, and no control. The differences in the flora composition, ground beetle fauna and micro arthropods were measured. Forestation using sub soiling results in a significant different flora. Forest species disappears, wind dispersed species dominates. The flora composition reflects the nitrogen status of the soil. Mechanical weeding increases nitrogen level of the soil. Soil living collembolans are significantly negatively influenced by mechanical soil treatment.

In the second study the fauna on the trees and the ground vegetation in conventional and organic Christmas tree plantations was investigated during two years. Diversity analysis shows no significant differences between the fauna on the organic Christmas trees compared to the conventional ones. On the other hand, there was a significant difference in the ground flora between the two types of plantations. Plant diversity is significantly higher in the organic plantations.

# Direct Seeding of Woody Plants as an Alternative to Traditional Plantations

*Agnès Sourisseau[1], Henri Frochot[2], Philippe Balandier[3,4], Ian Willoughby[5]*

[1] Independent Landscaper, 60 rue des Orteaux et 95 rue d'Avron, F-75020 Paris, France -* Corresponding author. Email: asourisseau@gmail.com, tel. +33 6 25 97 45 60
[2] INRA, UMR1092 LERFOB, F-54280 Champenoux, France
[3] Cemagref, Research Unit on Forest Ecosystems, Domaine des Barres, F-45290 Nogent sur Vernisson,
[4] INRA, UMR547 PIAF, F-63100 Clermont-Ferrand, France
[5] Forest Research, Alice Holt Lodge, Farnham, GU10 4LH, UK

**Key words:** direct seeding of woody plants, biodiversity, mulch, controlled herbaceous vegetation, hydraulic seeding

### Introduction

There is a very real need for afforestation in areas degraded by large-scale infrastructure works or environmental cleanup operations, but this differs from the traditional uses of forestry. The timber profitability aspect is not the primary objective. However, the creation of biomass for the development of wood energy is not to be overlooked. The implementation cost has to be attractive, and the value this type of afforestation adds to the environment and landscape is a central consideration. It is in this context – the reforestation of degraded areas – that a research program has been in operation since 2001, within the framework of the management of railways' green dependencies. Réseau Ferrée de France has financed this research program with a view to developing alternative plantation techniques that use less inputs than traditional techniques. Direct seeding is one of the three axes constituting this research and development program (the two others concern biodegradable mulches and seed traps as hedge structures without plantation).

The aim of research on and development of the direct seeding of woody plants:
Monospecific woody plant seeding is known and used unevenly across France as a function of the different afforestation policies of individual departments. The seedings are done with seeds not presenting homogeneous dormancy properties (mainly oak, walnut, sweet chestnut). The materials used are predominantly agricultural, and weed vegetation is removed either mechanically or chemically. Technical and scientific data relating to the direct seeding of mixed woody plants is rare. Therefore, the aims of this research were as follows:
- Define dormancy breaking conditions of seeds by species.
- Define the best seeding methods in terms of cost and implementation difficulty
- Evaluate the influence of seeding techniques on the growth and development of seedings.
- Define the best seeding period by species.
- Evaluate the influence of growth medium on the growth and development of seedings
- Define the quantities of seeds to be sown by species (as a function of seeding techniques) to reach a goal of 10 000 plantlets per hectare in the first year, tending in the long term towards three distinct types of ecosystem: low shrubbery, high shrubbery and oak.
- Produce a technico-economic assessment of the techniques tested.

### Materials and Method

The available technical and scientific literature, as well as data collected on experimental farms (in Montoldre and Nancy, both set up in 2003 as part of this research) made it possible to orient choices before creating a full-scale testing site on 35 hectares east of Paris in 2006.

Choices were as follows:

- Number of seeds sown : 500,000 seeds per hectare for an anticipated first year yield of 10,000 plantlets per hectare
- Unprepared seeds used (greater availability and more flexibility in terms of seedtime)
- Seedtime : Spring
- Cover crops used; definition of mixtures:

| Species mixture H1 | Quantity/ha (Kg) | Species Mixture H2 | Quantity/ha (Kg) |
|---|---|---|---|
| *Agrostemma githago* | 0.5 | *Secale cereale L.* | 23.0 |
| *Avena sativa* | 15 | *Fagopyrum esculentum* | 23.0 |
| *Fagopyrum esculentum* | 10 | *Phacelia tanacetifolia Benth.* | 3.0 |
| *Linum usitatissimum* | 5 | *Lotus corniculatus L.* | 1.5 |
| *Lotus corniculatus* | 1.5 | *Festuca ovina* | 17.0 |
| *Lupinus luteus* | 2 | *Trifolium pratense L* | 1.0 |
| *Malva meluca* | 2 | *Trifolium subterraneum* | 3.0 |
| *Papaver rhoas* | 0.3 | *Sinapsis alba* | 3.0 |
| *Phacelia tanacetifolia* | 3 | **Total** | **74.5** |
| *Raphanus sativus* | 2 | | |
| *Secale multicaule* | 15 | | |
| *Sinapis alba* | 4 | | |
| **Total** | **60.3** | | |

- Choice of woody plant mixtures (endemic, flexible woody plants constituting common shrubby and oak ecosystems)

| Mixture L1 small seeds: | Dose/ha in kg | No. seeds /Kg | No. seeds /ha |
|---|---|---|---|
| *ACER CAMPESTRE* | 0.700 kg | 12,000 | 8,400 |
| *AMELANCHIER OVALIS* | 0.700 kg | 200,000 | 140,000 |
| *CARPINUS BETULUS* | 2.400 kg | 21,500 | 51,600 |
| *CORNUS MAS* | 3.500 kg | 4,600 | 16,100 |
| *CORNUS SANGUINEA* | 0.700 kg | 17,000 | 11,900 |
| *FRAXINUS EXCELSIOR* | 0.800 kg | 15,000 | 12,000 |
| *HIPPOPHAE RHAMNOIDES* | 0.200 kg | 110,000 | 22,000 |
| *MALUS SYLVESTRIS* | 0.400 kg | 28,000 | 11,200 |
| *PRUNUS AVIUM* | 1.200 kg | 6,000 | 7,200 |
| *PRUNUS MAHALEB* | 0.300 kg | 13,000 | 3,900 |
| *PRUNUS SPINOSA* | 0.700 kg | 4,900 | 3,430 |
| *PYRUS COMMUNIS* | 0.220 kg | 35,000 | 7,700 |
| *RHAMNUS CATHARTICA* | 0.600 kg | 60,000 | 36,000 |
| *ROSA CANINA* | 0.200 kg | 50,000 | 10,000 |
| *SAMBUCUS NIGRA* | 0.200 kg | 300,000 | 60,000 |
| *SORBUS ARIA* | 0.250 kg | 50,000 | 12,500 |
| *VIBURNUM LANTANA* | 2.700 kg | 32,000 | 86,400 |
| **TOTAL** | **15.770 kg** | **959,000** | **500** |

| Mixture L2 large seeds: | Dose/ha in kg | No. seeds /Kg | No. seeds /ha |
|---|---|---|---|
| *CORYLUS AVELLANA* | 7.100 kg | 400 | 2,840 |
| *QUERCUS PETRAEA* | 55.000 kg | 245 | 13,475 |
| **TOTAL** | **62.100 kg** | **645** | **16,315** |

| Mixture L3 | Dose/ha in kg | No. seeds /Kg | No. seeds /ha |
|---|---|---|---|
| *ACER CAMPESTRE* | 0.350 kg | 12,000 | 4,200 |
| *CARPINUS BETULUS* | 1.200 kg | 21,500 | 25,800 |
| *BETULA PENDULA* | 0.210 kg | 2,000,000 | 420,000 |
| *CORNUS SANGUINEA* | 0.350 kg | 17,000 | 5,950 |
| *FRAXINUS EXCELSIOR* | 0.400 kg | 15,000 | 6,000 |
| *MALUS SYLVESTRIS* | 0.200 kg | 28,000 | 5,600 |
| *PRUNUS AVIUM* | 0.600 kg | 6,000 | 3,600 |
| *PRUNUS MAHALEB* | 0.150 kg | 13,000 | 1,950 |
| *SAMBUCUS NIGRA* | 0.100 kg | 300,000 | 30,000 |
| *SORBUS ARIA* | 0.125 kg | 50,000 | 6,250 |
| *TOTAL* | **3.685 kg** | **2,462,500** | **509,350** |

| Mixture L5 on embankment | Dose/ha in kg | No. seeds /Kg | No. seeds /ha |
|---|---|---|---|
| *AMELANCHIER OVALIS* | 0.700 kg | 200,000 | 140,000 |
| *CORNUS MAS* | 1.000 kg | 4,600 | 4,600 |
| *CORNUS SANGUINEA* | 1.700 kg | 17,000 | 28,900 |
| *HIPPOPHAE RHAMNOIDES* | 0.300 kg | 110,000 | 33,000 |
| *LABURNUM ANAGYROÏDES* | 1.600 kg | 34,000 | 54,400 |
| *PRUNUS MAHALEB* | 1.500 kg | 13,000 | 19,500 |
| *PRUNUS SPINOSA* | 1.500 kg | 4,900 | 7,350 |
| *RHAMNUS CATHARTICA* | 1.500 kg | 60,000 | 90,000 |
| *ROSA CANINA* | 0.500 kg | 50,000 | 25,000 |
| *VIBURNUM LANTANA* | 2.000 kg | 32,000 | 64,000 |
| **TOTAL** | **12.300 kg** | **525,500** | **466,750** |

## Full-scale testing on 35 hectares of disused railway land east of Paris

Three main tests were conducted:

The different methods were divided into 120 experimental plots measuring approximately 800 m².

Test 1 : Comparison of agricultural seeding techniques and hydraulic seeding techniques. With and without accompanying controlled herbaceous vegetation. Two seeding densities were tested corresponding to mixtures L1 and L3. The methods were repeated in 3 complete blocks.

Test 2 : Woody plant seeding with a hydroseeder on an embankment, consisting of 4 repetitions in blocks corresponding to the four directions East/West/South/North on reworked soil, superficial vegetable soil (10 cm). 5 methods of seeding Mixture L5: with controlled herbaceous vegetation, on bare soil, with herbaceous mixture H2, on biodegradable felt, on wood fibre.

Test 3 : Woody plant seeding with mulch, without herbaceous accompaniment. Hydraulic or agricultural seeding techniques. Two thicknesses of mulch tested with two seeding densities.

Type of mulch tested (with two thicknesses: 2 or 6 cm):

Coconut shavings – Hemp straw – Flax straw – Wood fibre – 12/25 gravel – compost

## Results and discussion

In spite of the difficulty of implementing protocols – related to the significant influence of the structure, which made it difficult to control work carried out by companies, as well as predation by numerous rodents, birds, deer and especially rabbits – the result of 15,000 plants per hectare was confirmed on the third year of monitoring. The best results were obtained on the mulches, which where the most expensive techniques to implement, though they were still less costly than traditional plantations. These techniques seem to offer a promising avenue; whichever mulch is used, results are better than on bare soil. The accompanying herbaceous cover, which was moderately successful, remains more favourable to woody plants than seeding on bare soil. Among the different seeding techniques, those enabling seeds to be buried are more favourable. In fact, plots seeded using agricultural techniques yield more woody plants. As for weather and scheduling issues, it was not possible to work on all experimental plots simultaneously, and two types of preparation were carried out prior to the seedings for Test 1 (fine or coarse tilling of the soil). Effects on the expression of herbaceous flora were observed. Additional tests would enable these observations to be taken further.

The experimental plots on the Claye-Souilly site present more or less controlled varieties of fallow land. They evolve over the course of the seasons and offer another approach to implementing afforestation, based on taking account of vegetation succession dynamics. It is a whole aesthetic that might not yet meet planners' and residents' expectations, but responds to real ecological and biological issues, at a much lower cost than traditional plantations. These techniques need neither inputs nor maintenance after implementation. Woody plant seedings take more time before they are recognised as afforestation, but they can have interesting landscape results and militate in favour of biodiversity. The use of this type of technique is clearly relevant to the restoration of areas disturbed by anthropic activity as well as to the hundreds of hectares of disused railway land; but it is also of particular interest to regions anxious to regain spaces that appear natural while using durable techniques. The potentialities of these techniques for the production of energy wood are clear; the potentialities for timber still need to be studied. Each year of additional monitoring will bring results likely to enable these techniques to be developed.

# Seed dormancy and consequences for direct tree seeding

*Henri Frochot[1], Philippe Balandier[2,3], Agnès Sourisseau[4]*

[1] INRA, UMR1092 LERFOB, F-54280 Champenoux, France, Frochot@nancy.inra.fr; henri.frochot@orange.fr
[2] Cemagref, UR EFNO, Nogent sur Vernisson, France
[3] INRA, UMR547 PIAF, Clermont-Ferrand, France
[4] Independent Landscaper, Paris, France

**Key words**
Afforestation, direct seeding, dormancy, seed, tree

**Introduction**
Whereas direct tree seeding was probably used extensively in France in the past, it is currently only employed for the reforestation of *Pinus pinaster* and some species with big seeds such as oak. Its interests are to allow a better seedling establishment and a reduced cost than with tree plantation. However many problems must still be solved. One is linked to seed dormancy (Finch-Savage and Leubner-Metzger 2006). Seeds of forest trees are frequently dormant when harvested or after a period of storage and their germination needs the release of dormancy, either by exposition to natural climate, or by artificial means when known (Willoughby et al. 2004). In the latest case pretreated seeds must be sown at a given period driven by the date of dormancy breaking, with no possibility to factor in climatic conditions. They often require specific conditions of moisture and temperature, not easy to observe in afforestation works.

Non-treated dormant seeds allow a better flexibility, especially for the date of sowing. The process of dormancy breaking by natural conditions theoretically leads to a seedling emergence during favourable soil and climatic conditions. However for most forest tree species with the exception of a few species particularly used (Suska et al. 1994), the conditions for dormancy breaking in the nature are badly known or unknown. Therefore we studied those conditions in a controlled experiment for 20 species (Frochot and Balandier 2005).

**Materiel and methods**
The experiment took place in the nursery of INRA Nancy (North-East France). Twenty woody species of the local flora were selected according to 3 successional stages after field abandonment:
- shrubs: *Amelanchier ovalis, Cornus mas, Cornus sanguinea, Hippophae rhamnoides, Laburnum anagyroides, Prunus spinosa, Rosa canina, Rhamnus cathartica, Viburnum lantana*
- mid-storey fruit trees: *Malus sylvestris, Prunus mahaleb, Pyrus pyraster, Sambucus nigra, Sorbus aria*
- main-storey trees : *Acer campestre, Betula pendula, Carpinus betulus, Fagus sylvatica, Fraxinus excelsior, Quercus petraea*

The seeds were not pretreated but *Fagus* as a reference and *Quercus* that was pregerminated. From the literature the dormancy profundity often expressed in months of dormancy length ranged from 0 month (*Betula, Laburnum*), 2-3 months (*Hippophae, Rhamnus*), 3-6 months (*Acer, Cornus sanguinea, Malus, Pyrus, Sambucus, Sorbus, Viburnum*), 6-10 months (*Amelanchier, Carpinus, Prunus mahaleb, Prunus spinosa*) and 10-14 months (*Cornus mas, Fraxinus, Rosa*).

The seeds were sown on 1.5 m long line in spring (20-22 May) or in autumn (20-21 October) 2003, buried or not into the soil and watered/shaded (nursery method) or not, each modality being replicated 4 times. The seed number sown was calculated from data on the potential germination rate given by the seed merchants in order to have approximately 50 seedlings on each line. Seedling number and mortality was recorded every 15 (in period of active emergence) or 30 days during 3 years.

## Results

*Seedling emergence*

*Betula* was eliminated from the analysis due to a very low emergence rate. The first year the species with treated seeds (*Fagus* and *Quercus*), the species with no dormancy (*Laburnum*) or weak dormancy (*Hippophae*, *Rhamnus*) and one species with a moderate dormancy (*Viburnum*) had emerged in 1 to 8 weeks after the sowing, despite the conditions of scorching heat of 2003. The second year all the species sown in spring that did not emerged the first year and all the species sown in autumn produced seedlings, with two exceptions for the autumn sowing (*Cornus mas* and *Fraxinus*) with a particularly deep dormancy.

The spring sowing had a mean emergence rate (seedling number / seed number) of 33 % (from 4 to 70% depending on the species) and that of autumn 13% (from 4 to 39%). At species level the spring sowing had always higher or at least equal emergence rates than those of autumn (table 1) and it was even 2 to 4 times higher for 6 species (*Acer*, *Prunus mahaleb*, *P. spinosa*, *Rosa*, *Rhamnus*, *Sambucus*).

*Table 1. Factors affecting the seedling emergence and mortality rates of 20 species sown in nursery in Nancy, France*

| Factor | Modality | Emergence rate | Mortality rate |
|---|---|---|---|
| Season of sowing | Spring / Autumn | Spring >> autumn | Autumn > Spring |
| Modality of sowing | Buried / not buried | Buried >> not buried | Not buried > buried |
| Soil watering | Irrigation / no irrigation | Small or no improvement | No effect |
| Shading | Shading net / no shade | Small or no improvement | Small or no increase |

The seedling emergence rate was higher (1 to 25 times depending on species) when seeds were buried in the soil for all species but Amelanchier for which it was equivalent. Watering the soil or shading did not improve the emergence rate except during the scorching heat of 2003 where the improvement of seedling emergence was evident.

For most species and for the most favourable conditions (spring sowing with buried seeds), seedling emergence rates were generally 1 to 4 times higher than the rates given by the seed merchants (with two exceptions *Rhamnus* and *viburnum* with a 0.5 times lower rate). The rates were even 10 times higher for *Sambucus* and *Hippophae*.

*Seedling mortality*

At the end of 2004 the mean seedling mortality rate was 15% (from 7 to 45% depending on the species) for the species sown in spring 2003 and 27% (from 15 to 59%) for the autumn 2003 sowing (with two exceptions *Rhamnus* and *Viburnum* with a lower mortality rate for the autumn sowing) (table 1). Improving soil water content did not affect the mortality rate. A factor that strongly increased the mortality rate was the seedling density on the line, sometimes much greater than the 50 seedlings expected (400 and 600 seedlings m$^{-1}$ for *Hypophae* and *Sambucus*, respectively). If such densities were excluded from the analysis, the mean mortality rate was close to 10% (from 6 to 18%). The shade increased the mortality for *Rosa*,

probably due to the presence of a rust favoured by the moisture under the shading net. The seeds of *Quercus* and *Fagus* sown in autumn were predated by small rodents.

## Discussion

The dormancy release was generally good leading to a seedling emergence rate higher than the one given by the seed merchants. For dormancy profundity results are in agreement with data of the literature. For the seeds sown in spring, dormancy was actually broken after 10 to 11 months, including *Fraxinus* and *Cornus mas* with a very deep dormancy, whereas for the autumn sowing, with only 5 to 6 months of exposure to natural conditions, the emergence rate was lower, suggesting a partial dormancy release. However some species sown in autumn with a low dormancy profundity (3-6 months) had also a lower emergence rate; this result suggests that the alternation of drought and humidity periods during the summer could play a non negligible role in the process of dormancy release.

From a practical point of view, results are clearly in favour of a spring sowing, with buried seeds, what leads to more and healthy seedlings. The success rate varied from 2 to 58%, with a rate higher than 20% for most species, which can be used to adapt the number of seeds to sow. Species with a weak seed dormancy will emerge a few months after the spring sowing, whereas species with deep seed dormancy will emerge a year latter after dormancy breaking by the summer, autumn and winter conditions. Consequently using a mixture of species with different seed dormancy properties leads to a better flexibility in the technique of direct tree seeding. However this result must be counter-balanced in the natural conditions by the activity of rodents, particularly during winter and for the biggest seeds (De Steven 1991).

Finally, it must be underlined that the environmental conditions (light and moisture) may not have an important role on the seedling emergence stage, except for exceptional conditions as the scorching heat of 2003. However, these conditions of light and moisture become fundamental for the seedling growth after emergence (De Steven 1991; Balandier et al. 2009).

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# Mechanical site preparation for vegetation control during restoration of oak forests: Early growth and survival in *Quercus robur* seedlings

*Magnus Löf[1], Maria Birkedal[1]*

1) Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, P.O. Box 49
S-230 53 Alnarp
Sweden
magnus.lof@ess.slu.se

**Key words**
Direct seeding, planting, soil preparation, weed control

## Introduction

Control of natural vegetation during reforestation is necessary to avoid extended rotation time and the need to replace dead seedlings. The use of herbicides is restricted in Sweden and there is a need for effective alternatives. Therefore, mechanical site preparation is carried out on many sites (Anonymous, 2008). Disc trenching accounts for the majority of the treated area and the other most common treatments are mounding or patch scarification. Mounding site preparation is an old mechanical site preparation method that has attracted new attention (Sutton, 1993). It has become an alternative to other methods, especially in northern boreal coniferous forest sites (Hallsby and Örlander, 2004). Little research has been done on mounding site preparation in the temperate forest zone.

During reforestation with oak, planting of bare-root seedlings is common practice. This is very costly because seedlings are expensive and need protection from browsing animals. Therefore, the development of alternative methods that reduce the regeneration costs for oak are needed. Direct seeding can be such an alternative. When successful, the cost may be less than half that of establishing a stand using planting (Bullard et al., 1992). However, there are several factors, two of which are more severe, that often contribute to regeneration failures when using direct seeding compared to planting. The first factor is rodents, which can disperse and consume buried acorns (Madsen and Löf, 2005). The second factor is the presence of herbaceous vegetation that competes with the newly established small seedlings. Mechanical site preparation not only aids the control of competing vegetation but also influences the amount and distribution of rodent habitat (Dey et al., 2008). Thus, studies of mechanical site preparation are important for both the development of strategies for successful direct seeding, and planting, of oak.

The objectives of the study were to: (1) Evaluate the effectiveness of various mechanical site preparation methods for vegetation control and (2) evaluate survival and growth response in planted and sown oak seedlings following different mechanical site preparation methods.

## Material and methods

This paper is based on two field experiments, both using randomized block designs with four replications, and monitored over three growing seasons. The first was established in Skarhult experimental forest in the southernmost part of Sweden in 2002. See Löf et al. (2006) for

more details concerning research design. The treatments were: Herbicide (H); Mounding site preparation (MSP); Mounding site preparation plus herbicide (MSP+H) and untreated control (C). MSP treatment was constructed in strips, also called bedding. In each treatment, bare-root oak seedlings were planted in the end of April 2002. In the treatments with herbicide, glyphosate were applied in early June and middle of July each growing season from 2002 to 2004. In each treatment the coverage (%) of herbaceous vegetation and seedling growth (stem base diameter) were measured in the end of 2004.

The second experiment was established in Asa experimental forest in southern Sweden in 2006. The treatments were: Mounding site preparation (MSP); Disc trenching (DT); Patch scarification (PS); Top soil removal (TSR) and untreated control (C). The MSP treatment was constructed as individual mounds, and in the TSR treatments the whole treatments plots (20 × 15 m) were treated. Direct seeding was carried out in the end of May 2006. In each treatment the biomass of herbaceous vegetation and seedling growth (stem base diameter) were measured in the end of 2008.

### Results and discussion

In the first experiment, the coverage of ground vegetation was efficiently controlled by H treatment, whereas no such effect was found with MSP treatment (Table 1). In contrast, MSP treatment reduced the amount of biomass of ground vegetation in the second experiment, and was more efficient compared with the other mechanical site preparation methods. Since no measurement of biomass of ground vegetation was carried out in the first study, it is difficult to compare ground vegetation in the two studies. However, it is most likely that coverage does not correspond to biomass, why ground vegetation probably, to some degree, was controlled by the MSP treatment also in the first study.

*Table 1. Mean amount of ground vegetation, established seedlings and stem base diameter in seedlings after three growing seasons following planting and direct seeding in four and five treatments, respectively.*

| Treatment | Ground vegetation | Established seedlings, % | Growth of seedlings, mm |
|---|---|---|---|
| **Planted seedlings in 2002** | % | | |
| C | 96 | 58 ± 7 | 9.0 ± 0.3 |
| H | 12 | 90 ± 3 | 12.4 ± 0.2 |
| MSP | 96 | 88 ± 3 | 11.4 ± 0.2 |
| MSP+H | 7 | 91 ± 1 | 15.3 ± 0.6 |
| **Direct seeding in 2006** | Ton, ha$^{-1}$ | | |
| C | 206 | 28 ± 4 | 3.7 ± 0.1 |
| DT | 101 | 31 ± 4 | 4.3 ± 0.3 |
| PS | 92 | 37 ± 6 | 4.5 ± 0.5 |
| TSR | 68 | 40 ± 2 | 4.2 ± 0.1 |
| MSP | 45 | 41 ± 3 | 5.5 ± 0.3 |

In the first study, survival rate in seedlings was lower in the C treatment compared with the other treatments. Something that probably was a result of a combination of vole damage and competition with ground vegetation during the first growing season in this treatment (Löf et al. 2006). The MSP treatment seems to be equally efficient as the H treatment in promoting survival in planted seedlings. In the second study, the amount of established seedlings increased with intensity of the mechanical site preparation method. The reason for this can not be deduced from our data, but might be due to lower activity of rodents when ground vegetation is controlled, or due to a combination of reduced rodent activity and reduced competition from ground vegetation.

As expected, growth in seedlings increased when ground vegetation was controlled with herbicides. However, also MSP treatment alone improved growth in both experiments. This is in line with findings by Gemmel et al. (1996) and Patterson and Adams (2003). Mechanical site preparation, such as mounding, influences both the amount of competing vegetation and the soil conditions and the specific cause of any positive effects is often not known, or at least difficult to determine. However, in the second experiment, soil temperatures increased with mounding in comparison with the other treatments (data not shown). For oak, growth in seedlings is promoted by increasing soil temperatures (Lyr, 1996). Thus, increased soil temperature in combination with reduced competition from vegetation might explain the positive growth response in MSP treatment.

We conclude that mounding site preparation can be an alternative to the use of herbicides for controlling ground vegetation during reforestation with oak.

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# Direct seeding of 11 tree species in Danish conifer plantations at sandy sites

_Palle Madsen[1], Anna Thormann[2], Finn A. Jensen[3], Torben L. Madsen[4] and Marco Cosme[1]_

[1] Forest & Landscape Denmark, University of Copenhagen, Vedelsgade 6, DK-7100 Vejle, Denmark, pam@life.ku.dk
[2] Danish Forest and Nature Agency
[3] HedeDanmark a/s
[4] Store Hjøllund Plantage A/S

**Key words**
Direct seeding, competition, regeneration, restoration, _Pseudotsuga_, _Pinus_, _Picea, Abies, Larix, Fagus, Quercus, Betula, Tilia_

## Introduction

About two third of the Danish forest area is conifer plantations and it is primarily located at poor sandy sites in the western part of the country. The main species is the non-native and off-site planted Norway spruce (_Picea abies_) which is poorly adapted to the mild and windy Atlantic climate. Additionally, the various climate change scenarios make the future look even more uncertain. Sitka spruce (_Picea sitchensis_) is yet another very common and important non-native species in Danish forestry that suffer from drought followed by insect attacks. As such there is in Denmark as in the rest of Europe a need for forest restoration and adaptive management to increase forest stability for the present as well as the future environmental conditions (Ammer et al. 2008, Hahn et al. 2005, Madsen et al. 2005, Spiecker et al. 2004). The native broadleaved tree species are usually viewed as the best site-adapted species and therefore the best choice to improve forest resistance and adaptability. Among the productive conifer species only the Scots pine (_Pinus sylvestris_) is native to Denmark. However, among the non-native conifer species there are several species - e.g. Douglas fir (_Pseudotsuga menziesii_), Silver fir (_Abies alba)_, Larch (_Larix sp._) - that have proved to be well adapted to Danish environmental conditions particularly at sandy soils. Other species, like lodgepole pine (_Pinus contorta_) may not be so well adapted, but have demonstrated high productivity and regeneration potential, which is interesting in the context of bioenergy production.

Madsen et al. (2005) describes how the barren heathland that once dominated large proportions of the country since the mid-19th century has been subject to major land reclamation and afforestation programmes to recreate landscape productivity and sustained living conditions for people. Accordingly, the landscape has in general shown dramatically improved soil fertility and micro-climatic conditions and now it is possible and highly relevant to consider establishment of several broadleaved species like beech (_Fagus sylvatica_), oak (_Quercus sp._), birch (_Betula sp._) and lime (_Tilia cordata_).

The restoration challenge is to a large extent a regeneration challenge. The regeneration conditions at these sandy sites are, however, still relatively difficult due to drought, frost, vegetation competition and deer browse. These are factors that easily lead to regeneration costs that are high considering the very long-term perspective of the investments in such efforts. The common regeneration technique is based on planting relative large (2-4 years old) nursery stock. Direct seeding can potentially reduce the regeneration cost to 50% or less the cost of conventional planting (Bullard et al., 1992, Löf et al. 2004; Madsen and Löf

2005). Direct seeding offers – if successful - high stock density at low cost.

The main disadvantage of direct seeding is that the most vulnerable stages of seedling development and establishment in the forest regeneration process are taking place under the more or less uncontrolled and sometimes harsh conditions of the regeneration sites. Those stages are the seed, the germinating seed, and the emerging seedling. Therefore, direct seeding is less reliable than planting and various biotic as well as abiotic factors like rodents, birds, deer and frost may eat, damage or kill the seeds and young and vulnerable seedlings (Willoughby et al. 2004). Further, the directly sown seedlings may due to their small size the first growing seasons potentially be less competitive relative to the forest floor or field vegetation and as such the vegetation management aspects are higly relevant and important in the direct seeding context.

Most studies on direct seeding in the temperate zone have opposite to those carried out in the boreal zone focussed at broadleaved species. The coniferous species – native as well as well adapted non-native species – are, however, highly relevant to study, too.

The aim of our study was (1) to study the reliability of direct seeding as a means to regenerate a number of mainly conifer species at poor sandy sites using simple techniques, (2) to study the vegetation management aspects including nurse crop and seedling density effects on survival and height growth direct seeded regenerations.

**Materials and methods**
Our study comprises two sets of experiments – a small scale pilot study established in the spring of 1997 and a study in a close-to-practise experiment established in the spring of 2002.

*Pilot experiment*
We established in May 1997 the pilot experiments at eight sandy sites in the western part of Jutland and in the northern part of Zealand under mature conifer shelterwoods (Norway spruce, Sitka spruce, Douglas fir, silver fir or Scots pine). 12 treatments replicated five times were established in 60 small (0.2 m²) plots at each site. At each site the treatments were combinations of four species separately sown in three seedbed types. The four sown species were Scots pine, Douglas fir, silver fir as well as either Norway spruce or Sitka spruce as reference species depending on the whether the site was near the sea (Sitka spruce) or not (Norway spruce). The three seedbeds were: (1) undisturbed forest floor, (2) mineral soil seedbed with the organic topsoil scraped off and the mineral soil exposed, (3) like (2) but including superficial soil-preparation to cover the seeds after sowing. Additionally, 25 plots were established of each seedbed (1) and (2) at at each site to monitor natural regeneration. The experiments were inventoried five, nine and 20 weeks after sowing in as well as in the 1999 autumn following the second growing season.

*Close-to-practise experiment*
 In the April 2002 we established another set of experiments at a scale which were larger and close-to-practise. The experiments included 11 species – both conifers and broadleaves – and seven sandy sites in the western part of Jutland. Based on the pilot experiment results we used the mineral soil seedbed including soil-preparation to cover the seeds following sowing at all sites. Additionally, tests of micro-preparation techniques like micro-preparation or various soil-preparation devices to create a mineral soil seedbed were tested at selected sites. The number of tree species involved at each site varied depending on site conditions, local management aims and the area of each experimental site. These experiments were –

opposite to the pilot experiments – mainly carried out at stormdamaged and thus clearcut areas following a heavy storm that hit the country in December 1999. One shelterwood site was included as well. Each experimental plot included typically 100 m of seedbed and the treatments were replicated three times at each site. The treatments were the various sown species at some sites and at other sites the treatments were combinations of the various seedbed treatments (e.g. micro-preparation versus no micro-preparation or tests of various soil-preparation devices). Nurse trees of hybrid larch (*Larix x eurolepsis*) and were planted at wide spacing to support recreation of forest conditions at the clearcut sites. The experiments were inventoried following the first (2002) and the third (2004) growing season. Additionally, sites with well established sown trees were inventoried in February 2009 and study the vegetation management aspects of regeneration density and the nurse trees.

## Results and discussion

Results will be presented at the conference. We conclude that by a careful match of species to site and by sowing mixtures of species it is possible by direct seeding to establish densely stocked regenerations of many desired species. This is possible at low cost and without a particular need for vegetation management i.e. control of vegetation competition. Some of the reliable and less demanding species are the pines and oak, whereas at sites protected by shelterwood silver fir, Douglas fir and spruce show generally good results. Lime, birch and hybrid larch did not show promising results in these studies. The sowings that successfully passed the initial phases of establishment showed further progress and good survival and growth with a limited or no dependence on intensive vegetation management measures.

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# Canopy effects on vegetation

*Sven Wagner[1], Holger Fischer[1], Franka Huth[1]*

1) Chair of silviculture, University of Technology, Dresden
Pienner Str. 8
D-01737 Tharandt
Germany
wagner@forst.tu-dresden.de

**Key words**
Single canopy tree effects; single species performance; competition; niche partitioning; silviculture

**Introduction**
The majority of research in the context of vegetation management is concerned about chemical and mechanical measures or prescribed burning to regulate competition between shrubs, grasses, herbs, ferns, and mosses on one hand and forest tree species regeneration on the other. Very often, the experiments conducted are laid out on open field. Under open field conditions, e.g. on former agricultural land or on clearcuts, forest practitioners are addicted to the above mentioned tools developed by scientific research. However, scientific research under environmental conditions characterized by the influence of old trees has clarified for long that species composition and species vitality of the tree-competing vegetation is considerably altered under trees canopy compared to open field conditions. As a raw statement it may be taken that most of those species are loosing much of their competitive ability under canopy conditions. Even so, the vitality of some light demanding tree seedlings and saplings may also be lower than on open field and this has for sure contributed to the preference in forest management to regenerate without canopy effects.

This review seeks to give some insights to simultaneous canopy effects on vegetation and on tree species regeneration. This will lead to the question whether forest management may benefit from canopy effects to reduce the competitiveness of unwanted species while keeping the vitality of desired tree species regeneration on economically acceptable/interesting level.

**Competition on open fields**
From studies on clearcuts we know that the outcome of the competition between ground vegetation and tree seedlings is species and site specific (Küßner et al., 2000). This should also apply to conditions under canopy.

**Canopy effects on vegetation/tree regeneration**
*Definition of canopy effects*
In this presentation canopy effects are understood as any relevant alteration of environmental conditions compared to open field due to the influence of forest stands. Those alterations are caused by trees, e.g. by their leaves, roots, branches, and bole. As a forest stand is an assembly of tree individuals it makes sense to have a closer look to the environmental alterations caused by single trees. This leads to the idea of zones of influence or ecological fields (Wu et al., 1985) of tree individuals. Many efforts have been undertaken to identify and de-

scribe ecological fields regarding the effects of tree individuals on light, water and nutrient availability so far. Other obvious effects are pollen, seed, and leaf dispersal of the trees. By those effects important further phenomena are driven within the forest ecosystem like the humus layer morphology (Wälder et al., 2008). The above mentioned effects are modified by tree species and stand density. As a substitute to stand density very often Relative Light Intensity (RLI) is communicated.

*Effects on vitality of single ground vegetation species*
Studies have been performed in which the density of the canopy is taken as an explanatory variable for biomass, height, coverage, allocation adaptations, and fecundity of a target species of the ground vegetation, e.g. velvet leaf blueberry (Moola & Mallik, 1998). However, it is clear that RLI cannot be taken as an isolated factor (Ellenberg, 1939). The relations between the explanatory variable and the vitality variables may be linear as well as non-linear. It seems that the type of this relationship depends on the species; but it often depends on the chosen scale of the explanatory variable as well. In predictions of tree seedlings diameter and height increment due to light availability, non-linear relations are well established (e.g. Pacala et al., 1994); but also in grass survival rate (Cole and Weltzin, 2005).

*Effects on multi species performance with special emphasis on tree regeneration*
Some publications may be found about canopy effects on vitality of species in mixtures of ground vegetation (Rice and Nagy, 2000; Mrotzek, 1998). A threshold of RLI may be detected below or above which the proportion of a particular species in a 2 species mixture changes dramatically (Bolte and Bilke, 1998). In those situations RLI is taken as an indicator variable for the outcome of the interspecific competition. There is also evidence that single canopy trees have a considerable effect on the competitive outcome between ground vegetation species (Kühlmann et al., 2001).
Situations are even more complex when the vitality of ground vegetation and tree species regeneration under canopy influence is taken into account simultaneously. From few studies under varying canopy closure we know that seedlings of tree species react different in height and diameter increment as well as in terms of survival rate on the combined effects of ground vegetation competition and canopy effects (Lüpke, 1982). However, it seems that the survival rate of shade tolerant tree species increases with decreasing RLI (Schmidt-Vogt, 1972) due to a more pronounced loss of ground vegetation vitality compared to the tree seedlings vitality. By this, a shift in the outcome of competition is observed along an intensity gradient of canopy effects.

## Silvicultural utilization of canopy effects/research needs
The effects of forest stands on the organisms and in particular on the vegetation of the forest ground are multiple and known for long (Ellenberg, 1939). However, detailed analysis of habitat demands of those organisms with regard to canopy tree species and canopy closure are rare; but see Ziesche and Roth (2008) for spiders of the soil-dwelling fauna.
Although in most of the published studies the observed phenomena were not explained by disentangling particular effects of canopy trees, it is clear that the tree species and the stands density are important factors. This simple statement may be more differentiated by taking the canopy effects on resource availability, i.e. light, nutrients and water, into account like it has been done by Davis et al. (1999). It seems that there is an urgent need for more research which is specifically conducted to ask for a niche partitioning between seedlings of tree species and species of ground vegetation regarding canopy effects by manner and intensity.
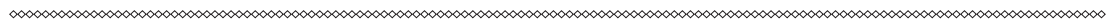
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# Competition for both light and below-ground resources determines the growth of seedlings and weeds in forest gaps

*Kjersti Holt Hanssen*

Norwegian Forest and Landscape Institute
P.O. Box 115
N-1431 Ås
Norway
kjersti.hanssen@skogoglandskap.no

**Key words**
Conifers, competition, selective cutting, trenching, weeds

## Introduction

Selective cutting and other small-scale harvesting methods may be used in areas with vivid weed growth to control the vegetation. However, the supply of both light and below-ground resources affects the growth and development of seedlings as well as weeds growing in the understory. The respective significance of these factors will vary with species and site, and may influence the applicability of different harvesting methods.

## Materials and methods

We studied the growth of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) seedlings in the understory, using three sites with selective cutting and group fellings in SE Norway. Seedlings were planted in plots with and without trenching in gaps of four different sizes, ranging from 20 m² (small gap) to 500 m² (group felling) and giving light levels from around 20 to 75 % of open sky. The trenches were around 40 cm deep, cutting off roots from neighbouring trees to prevent root competition for nutrients and water. After tree years seedlings were dug up and measured. Vegetation cover was also registered in the different plots. Differences in seedling growth characteristics and vegetation cover due to gap size and trenching were analysed using GLM.
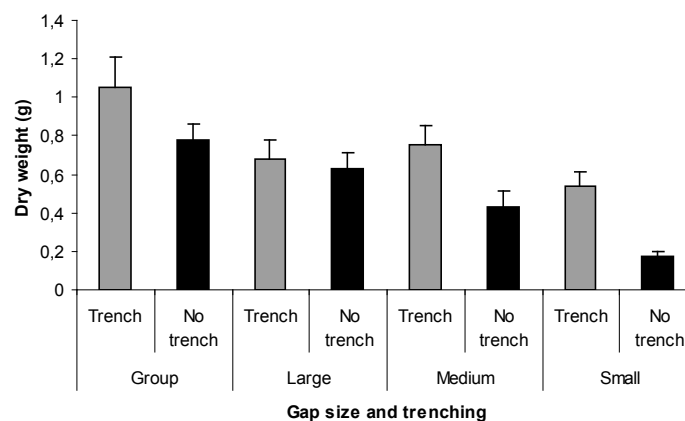


*Fig. 1. Dry weight of spruce seedlings for different combinations of gap sizes and trenching/no trenching. N = 18 for each treatment combination. Vertical lines indicate +SE.*

**Results and discussion**

Growth of both species was positively and significantly correlated with increasing gap size. This applied for height, diameter, shoot volume, needle length and needle number as well as total dry weight (Fig 1) for both spruce and pine seedlings. However, trenching also had a clear and significant positive effect on the same growth parameters. Also in the smallest gaps growth increased significantly with trenching, showing that light was not necessarily the limiting growth factor. For some of the growth parameters, there were interaction between gap size and trenching.

The growth of some weed species, especially wavy hair-grass (*Deschampsia flexuosa*) also increased significantly with both gap size and trenching. Average cover of this species after three growing seasons was for instance 75 % with trenching and 44 % without trenching. The vivid growth of this and other weeds may thus have hampered the growth of seedlings, especially in trenched plots and in the largest gaps. Nevertheless, the increased seedling growth with increasing gap size and trenching shows that competition for both light and below-ground resources matters under the studied conditions.

# Regeneration and diversification of Pinus halepensis stands in southern France: impacts of different vegetation and soil treatments

*Bernard Prévosto[1], Christian Ripert[1], Yogan Monnier[1], Aude Corbani[1]*

1) Cemagref, UR Ecosystèmes méditerranéens et risques, 3275 route Cézanne, CS 40061
13162 Aix-en-Provence cedex 5
France
bernard.prevosto@cemagref.fr

**Key words**
Soil preparation, recruitment, *Quercus ilex*, *Quercus pubescens*

**Introduction**

Mediterranean ecosystems are the result of a long history of natural and anthropogenic disturbances, which have generated a mosaic of vegetation structures including various types of lawns, shrublands and woodlands. Due to the regime of disturbances, terminal forest stages generally composed of broadleaves or a mixture of conifer-broadleaf species are scarce.

The Provence region in southern France typically fits such a frame. In this area Aleppo pine forests cover about 240 000 ha due first to the ability of this species to colonise lands after agricultural abandonment and second to its ability to regenerate after fire events.

The regeneration of Aleppo pine is considerably fire-dependent, and the role of fire in the dynamics of this species has been investigated in depth in the past (e.g. Daskalakou and Thanos 1996, Martínez-Sánchez et al. 1999, Pausas et al. 2003). However, the role of fire has been considerably reduced in many natural ecosystems due to anthropogenic fire suppression, and thus information on management strategies of Aleppo pine stands not submitted to fires is needed. Study of the successional pathways suggests that Aleppo pine forests are replaced by the oak species *Quercus ilex* and *Quercus pubescens*. Change from pine forests towards mixed conifer - broadleaf woodlands is a scenario promoted by forest managers as mixed stands are supposed to be more resilient to fire, insect outbreaks and susceptible to host a higher diversity (Jactel et al. 2006, Pausas et al. 2004, Vallejo et al. 2006). However this process is long and uncertain as it depends on numerous variables such as availability and proximity of seed sources, presence of seed vectors (mainly jay) and resistance of the initial vegetal community to colonisation.

Our study aims at providing management strategies allowing mature pine stand regeneration and enhancing oak establishment and survival. In this respect the effects of several soil and ground vegetation treatments have been evaluated on natural pine seedling recruitment and on the survival of introduced oak acorns.

**Material and Methods**

Experiment

A randomized block design was installed in a mature Aleppo pine stand near Avignon (Southern France) just after a partial cut by using 10 treatments resulting from the combination of two

slash treatments' disposal and five soil and ground vegetation treatments. The treatments were replicated four times in four 34 m × 82 m blocks. A total of forty 14m×14m plots (10plots/slash, soil and ground vegetation treatment) were installed.

The slash treatments consisted in i) manually removing the slash on half of each plot and ii) scattering this slash on the other half of the plot. The soil and ground vegetation treatments were i) mechanical ground vegetation chopping ii) chopping followed by scarification in one direction, iii) chopping followed by scarification in two perpendicular directions, iv) controlled fire and, v) control.

Pine regeneration measurements

In each plot, 15 subplots of 1 m$^2$ were regularly installed along five transects of 12 m length, except in plots with the control treatment and slash presence, where only 10 subplots were established. In each of the 580 subplots of the experiment, pine seedlings were counted and mapped using a 1 m$^2$ grid divided into 25 squares of 20 cm × 20 cm. Counting took place at the end of 2005, in June and December 2006 and 2007 and in December 2008.

Oak seeding and measurements

Acorns from *Quercus ilex* and *Quercus pubescens* were collected from trees located near the experimental site and in the same ecological site conditions. In November 2005, 800 sets of 3 acorns (half *Q. ilex*, half *Q. pubescens*) were sown at 3 cm depth using a wire mesh to prevent rodent predation. In November 2006, 800 sets of 3 acorns were sown again using the same procedure. In December 2006, 2007 and 2008, oak seedlings were counted, measured and the soil surface around each sowing point (radius = 25 cm) was described: cover in bare soil, stones, moss, grass, shrub, coarse woody fragments (>2 cm in diameter), litter and small woody fragments were visually estimated using an abundance dominance coefficient derived from the Braun–Blanquet method.

**Results and discussion**

Mean pine seedling density established at 1.7 seedling/m$^2$ at the end of 2008 but with huge differences according to the treatments (min 0.03, max 2.42 seedling/m$^2$) (Fig. 1A). Two groups of treatments emerged: control, low intensity fire (without slash), chopping on the one hand characterised by low pine regeneration and, scarification and high intensity fire on the other hand with higher values for pine densities (Fig. 1A). The treatments have led to drastic changes in soil surface elements, in particular grass cover (mainly *Brachypodium retusum*
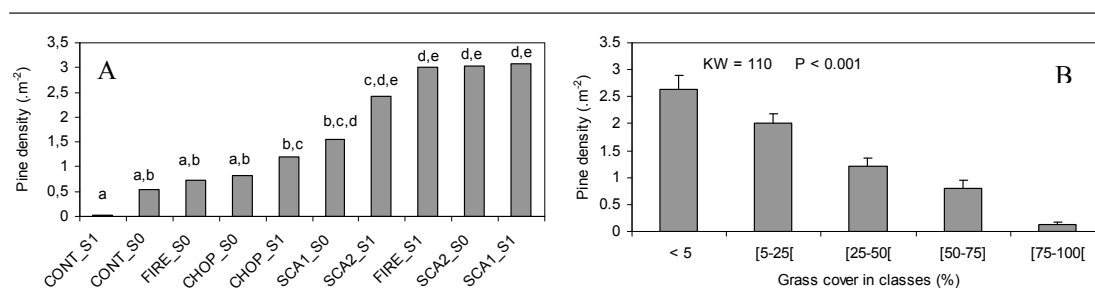


*Fig.1 A) Seedling density (December 2008) according to the different treatments. Different letters indicate significant difference (P < 0.05) between the treatments (Nemenyi test). Abbreviations are as follows: CONT: control, CHOP: chopping, SCA1: chopping + soil scarification in one direction, SCA2: chopping + soil scarification in two directions; FIRE: controlled fire, S0: no slash, and S1: presence of slash*

*B) Pine density according to the different grass cover classes, results from a Kruskal-Wallis test are indicated.*
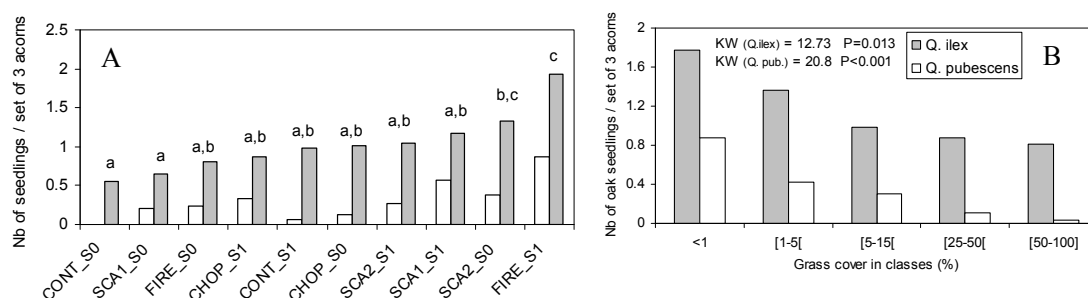
Fig. 2. A): Mean number of oak seedlings (June 2008) per set of three acorns according to the different treatments (see Fig.1 for labels denomination). Letters indicate statistical differences for Quercus ilex (P <0.05, Nemenyi test). B) Mean number of oak seedlings (June 2008) per set of three acorns according to grass cover in classes, results from a Kruskal-Wallis test are indicated.

in this study), which exerted a detrimental effect on pine density (Fig. 1B). Bare soil cover played an opposite role (data not shown). Relative failure of the first group of treatments can therefore be related to the absence of bare soil, at least the first year (control, chopping), and/or the fast development of competitive grass (low fire).

Survival of oak seedlings showed large differences according to:
i)   the oak species: at the end of 2008, mean number of Q ilex seedling per set of 3 acorns was 1.06 and only 0.32 for Q. pubescens,
ii)  the type of treatment (Fig. 2A): as for pine seedlings, scarification, high fire treatments were globally more favourable on oak survival than chopping, control and low fire treatments.
Soil cover also largely determined oak survival, in particular large coverage by grass species was associated to low survival (Fig. 2B).

This study showed that soil and ground vegetation treatments positively influenced pine recruitment and oak seedling survival as compared to the control. Scarification and prescribed burning with sufficient fire intensity had positive effects on pine and oak seedlings. By contrast, treatments producing low bare soil cover and enhancing grass development such as chopping and prescribed burning with low fire intensity were less favourable to pine or oak seedling survival.

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# Foundations of the cover crop technique and potential use in afforestation

*Philippe Balandier[1,2], Henri Frochot[3], Agnès Sourisseau[4]*

1) Cemagref, Research Unit on Forest Ecosystems, Domaine des Barres, F-45290 Nogent sur Vernisson, France, email: philippe.balandier@cemagref.fr
2) INRA, UMR547 PIAF, Clermont-Ferrand, France
3) INRA, UMR1092 LERFOB, Champenoux, France
4) Independent Landscaper, Paris, France

## Introduction

In many circumstances in afforestation, by tree plantation or by direct tree seeding, the quick development of very competitive herbaceous and shrubby species can compromise tree establishment (Balandier et al. 2006). At present, this vegetation is often controlled by chemical and mechanical operations, whereas they are criticized from an environmental point of view; some alternatives are under study (Willoughby et al. 2009). The cover crop technique (or cover plant), i.e. sowing in place of the spontaneous competitive vegetation (mainly perennial grasses) a cover plant mixture assumed to be less competitive, is an example of potential ecological engineering (Balandier et al., 2009). In addition with the control of potential weeds and reduction of competition for resources, the cover plants are thought to offer protection against frost and scorching temperatures to the young trees, or to avoid the water run-off encountered on bare soil.

Despite promising results obtained in some experiments, there are also a lot of negative data. The reasons of success or conversely failure of the cover plants to control weeds and establish young trees are not fully known or analysed. Actually the fundamental bases of the technique are not fully established.

## Monoculture or mixture?

In many circumstances using a single species to establish the cover was reported as a failure, either because the plant did not established well, or because conversely it developed too much and competed strongly with the young trees. Sowing a mixture of plants is a way of both securing the establishment of some species while avoiding a too large development of other species. In some experiments more than 20 species were used, annuals and perennials, with complementary phenologies and functional treats. The aim is to rapidly and permanently cover the soil in order to limit the development of weeds, often very light-requiring species, in addition with other functions such as the N fertilisation of soil with legume species, prevention of erosion with dense rooted species, etc. The reason of designing a mixture of species rather than using a single species is also that in a species community, species using different resources, or collecting resources at different places or at different periods can co-exist (niche theory). This principle was largely exploited to select species grown in association, and particularly crop and tree in agroforestry (Batish et al., 2008).

## The choice of species

However a huge work remains to do in the context of afforestation to select a sufficient number of species, not too competitive relative to young trees, well adapted for different site conditions and coexisting as a community. If we add also the principle of using only species present in

the local flora to avoid pollution by exotic species, the work becomes excessive. We know some species to avoid, and particularly those that are undesirable such as perennial grasses. For instance the Ray grass (*Lolium perenne*) is often used in different contexts as slope stabilisation, prevention of erosion, etc., whereas it is a strong competitor relative to most young trees. We obviously need a referential frame of plant functional treats that would allow to select species for a low competitiveness relative to tree, and having complementary features. This work has been done, at least partially, for some communities as pasture or meadow but still needs development in forest.

### What is the good technique to correctly sow different species?
The rapid development of cover plants after the sowing is fundamental to avoid the one of weeds at tree sowing or plantation. If in agriculture efficient guidelines have been available for a long time to sow most crop species, little is known for more uncommon or wild species. In many experiments, the failure of the cover plant technique is due to a very low emergence and development rate of the sown plants, or too late to play a significant rate. We identified that the sowing technique itself is often inappropriate to correctly sow a mixture of seeds with different sizes. Soil preparation must also be adapted to the chosen species, to the cultural antecedents of the site (Provendier et al. 2005). Again a large amount of work should be done on some aspects to improve the cover plant technique.

### The fundamental impact of predation
Seed predation by rodents and birds and damages on young trees by browsing animals are often reported in the literature as adverse factors for the success of afforestation, either by tree plantation or by direct tree seeding. Rodents and birds can obviously raise a non negligible amount of seeds of the cover plants, reducing the emergence rate accordingly. The role of insects such as ants is probably underestimated in that predation. In a controlled experiment in central France (Charensat) where cover plant seeds of different species were protected from birds and rodents by a wire netting, we observed an intense harvest of seeds by different insects. The role of other animals such as slugs is probably underestimated as well (observations at Claye-Souilly, Paris, France).

There are also interactions between the mixture composition and damages on young tree made by rodents and wild ungulates such as roe deer. Of course if some palatable plants make up the mixture of cover plants, damages on trees strongly increase. For instance legume species are known to attract rodents. Conversely some plants with spines or toxic compounds like alkaloids could keep away the predators; to our knowledge this track is not explored.

### Why using cover plants?
Despite this long list of drawbacks, cover plants proved in some cases that they can improve tree establishment, mostly in unfertile sites, at least in comparison with doing nothing, the use of herbicides still giving the best results (Balandier et al. 2009). They can also bring an added value, such as an increase of biodiversity, an improvement of the landscape if flower species are used, or other productions as honey if melliferous plants are used. Again these different aspects have not been really investigated to actually assess the ecological footprint of the technique.

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# Natural regeneration of Norway spruce on scarified clear-cuts in southeast Norway

*Aksel Granhus [1], Inger Sundheim Fløistad [2]*

1) Norwegian Forest and Landscape Institute
P.O. Box 115
NO–1431 Ås
Norway
aksel.granhus@skogoglandskap.no

2) Norwegian Institute for Agricultural and Environmental Research
Plant Health and Plant Protection Division
Høgskoleveien 7
NO–1432 Ås
Norway
inger.floistad@bioforsk.no

**Key words:** Picea abies, Site preparation, weed control

## Introduction

In Norway, natural regeneration after clear-cutting has become more widely practiced in stands of Norway spruce (*Picea abies* (L.) Karst.). In spruce stands, natural regeneration may be more problematic than on less fertile pine sites due to competition by several pioneer species, particularly the grass *Deschampsia flexuosa* L. Depending on vegetation type, a relatively thick humus layer may also severely hinder germination and early survival. To improve establishment, scarification may be necessary but may be less effective than on poorer sites. The results obtained with scarification for natural regeneration on sites of medium productivity are not well documented in Norway. Both variations in seed crops, availability of seed sources, and site conditions may contribute to a variable outcome.

In 2008, an inventory of clear-felled spruce stands was carried out within a large (37 000 ha) forest property in southeast Norway (Romedal og Stange almenninger). The overall aim was to evaluate the current regeneration strategy for spruce sites of medium site index within the property, a strategy which shifted from planting to natural regeneration in 2001.

## Materials and methods

The inventory was performed from late summer to fall of 2008, and was restricted to stands of site class G14 (dominant height 14 m at breast height age 40 years). A total of 104 stands were chosen, among objects scarified during 2001-2006, without subsequent planting. Most of the stands were harvested one or two growing seasons prior to scarification. Elevation varied from 250 to 570 m a.s.l.

In each stand, 15 circular plots sized 16 m$^2$ were distributed equally along three transects, each transect being laid out perpendicular to the longest axis of the stand. In each gross plot, we counted the total number of pines and spruce seedlings older than two years. Two-year old spruce seedlings occurred in great numbers in many plots, due to a very good seed year in 2006. These seedlings were counted separately within a smaller (inner) plot of size 1 m$^2$.

Regeneration establishment was assessed by means of seedling densities ha$^{-1}$ and the zero-plot percentage, i.e. the proportion of 4 m$^2$ plots without seedlings. For the sum of pine and older

spruce the zero-plot percentage was determined by dividing each gross plot into four quadrants of 4 m², and presence or absence of at least one seedling was registered in the field. For the two-year-old spruce, the zero-plot percentage was approximated by calculating the probability of a 4 m² plot being empty as follows:

Zero-plot percentage = 100 x (Proportion of empty 1m² plots)⁴

In each plot we also registered the vegetation type, as either cowberry woodland (*Vaccinio-Pinetum*), bilberry woodland (*Eu-Piceetum myrtilletosum*) or small fern type (*Eu-piceetum dryopteri-detosum*) (Fremstad 1997). The density of retained seed trees (mostly pine) was counted within a radius of 20 m from the plot centre. Additional stand attributes were either assessed as class variables in the field (proportion of stand edge composed of seed bearing trees, exposition, inclination) or obtained from stand inventory data (stand area, elevation in m a.s.l.). As establishment was also expected to be influenced by edge effects, an index that combines stand area with the proportion of stand edge with seed bearing trees (cutting class IV and V) was calculated as:

EDGE = (1+A)/(1+B)

Where A is a categorical variable accounting for the proportion of stand edge with seed bearing trees (0=0%, 1=1-33.3%, 2=33.3-66.6% and 3=66.7-100%), and B = stand area in ha.

Analyses of variance (Proc GLM) and logistic regression (Proc LOGISTIC) were run in SAS version 9.1 to analyse the regeneration results in relation to time since scarification, vegetation type, elevation, density of retained seed trees and the edge effect index. When we evaluated regeneration success in relation to the zero-plot percentage a threshold value of 20 was chosen. This is because 20 percent zero-plots (4 m²) correspond closely to a yield capacity of 100% compared with yield tables for Norway spruce (Braathe 1953, 1976).

**Results and Discussion**
Densities of two-year-old spruce seedlings declined rapidly with increasing time since scarification, and were less on bilberry and cowberry woodland than on the small fern vegetation type. The probability of reaching the target value also declined somewhat slower in stands classified to latter vegetation type. In accordance with this, both time since scarification (p=0.0004) and the interaction between time since scarification and vegetation type (p=0.0455) had significant impact on the probability of reaching a zero-plot percentage of 20 or lower for this age class (logistic regression analysis, cf. Fig. 1a). The frequency of zero-plots also tended to be lower on north and east facing slopes compared with level ground or slopes facing south- or westwards (p=0.0884, Fig. 1a). Additionally, the EDGE variable had significant effect (p=0.0127, Fig. 1b), with increasing stand area and lower proportions of seed bearing trees along the stand edge being associated with increasing zero plot percentage.

In contrast to the two-year-old seedlings, the abundance of spruce seedlings older than two years was lower (p=0.0133) in stands of the small fern vegetation type (mean = 419 seedlings ha⁻1), than on the other vegetation types (bilberry: 1477 seedlings ha⁻¹; cowberry: 1191 seedlings ha⁻¹). This difference compared with the two-year-old seedlings may be due to differences in pre-harvest standing volumes among stands of different vegetation types and that vigorous advance growth seedlings were included in the group of older seedlings. As with the two-year-old seedlings, we found a slightly higher density of older seedlings on north and east facing slopes (mean = 1340 seedlings ha⁻¹) than on other expositions (mean = 659 seedlings

ha⁻¹) (p=0.0522). Except for a markedly lower density in stands scarified in 2006 (p=0.0118, data not shown), there was no clear effect of time since scarification.

The density of pine seedlings was significantly higher on the cowberry woodland vegetation type (mean = 8388 seedlings ha⁻¹) than on bilberry woodland (mean = 3753 seedlings ha⁻¹) and the small fern vegetation type (3978 seedlings ha⁻¹) (p=0.0011). There were no significant differences among stands scarified in different years. Seedling densities correlated positively with the number of retained seed trees per ha⁻¹ and negatively with increasing elevation (p=0.0052 and 0.0164, respectively).

While a significant pine admixture will be secured in many of the stands, overall densities of pine and older spruce seedlings were usually too low to meet regeneration requirements. Successful regeneration of spruce relied largely upon one single seed year (2006), which often led to high seedling numbers in stands scarified shortly before the seed fall. Since 1998, 2006 was the only year with abundant seed production in this part of Norway (a good seed year was also expected in 2002, but seed crops were generally poor due to *Thekopsora areolata infection)*. The results of this study thus clearly illustrate the importance of proper timing of scarification with seed years when aiming to regenerate Norway spruce naturally.
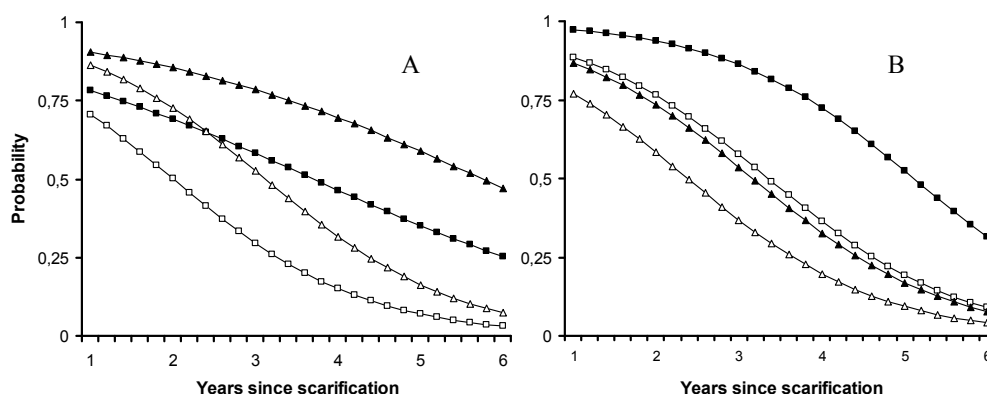


*Figure 1. Establishment of two-year-old seedlings, illustrated by the probability of obtaining a zero plot percentage of less than or equal to 20 after two years. The left part (A) shows the effect of vegetation type (black: small fern, white: cowberry or bilberry) and exposition (triangle = north or east facing; square = other) for a 15 ha stand with proportion of seed bearing trees along the stand perimeter between 33.3-66.6%. In B), the impact of seed bearing trees along the stand perimeter (white = 1-33.3%, black = >66.6%) and stand area (triangle = 2.5 ha; square = 0.5 ha) is illustrated for the cowberry and bilberry vegetation types (these vegetation types were pooled due to lack of significant differences).*

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# Natural regeneration after storm: positive and negative effects of vegetation on forest regeneration

*Marine DODET, Léon WEHRLEN, Florian VAST, Henri FROCHOT*

MGVF, Laboratoire d'Etude des Ressources Forêt-Bois, UMR 1092
INRA – F 54280 Champenoux, France
Tel : +33 3 83 39 40 44  - Fax : +33 3 83 39 40 34
mgvf@nancy.inra.fr

After storms, natural regeneration is sometimes sufficient to ensure forest renewal. Indeed, canopy opening favours the objective young tree seedlings installation, by increasing light their development needs. But light also promotes the installation of numerous new grass and other ligneous species, some of which – ferns, *Clematis*, perennial herbs and forbs, heliophiles – can endanger the seedlings survival and thus stop regeneration for many years.

Initial interventions of vegetation control to reduce heliophiles species and favour pioneers could avoid these blocking situations and even allow vegetation positive effects. The working factors complexity makes it necessary to well define the success and failure conditions of regeneration, and hence the necessary interventions to best use the natural regeneration potential. We designed a three-site experiment in north-eastern France in beech and oak stands, with four vegetation management and two predation control modalities in 2002, three years after the big storm of 1999. Two measurement campaigns took place in 2004 and 2008. The data analysis is currently in progress but while no modality effect was clearly demonstrated in 2004, it seems that the regeneration dynamics vary depending on the vegetation management modality in the recent observations.

The results have implications beyond the context of forest regenerations after storm. In particular, they provide important information on the effects of a more or less close canopy on the vegetation and regeneration dynamics.

# Natural regeneration of Pinus pinea L. in Tunisia as influenced by canopy cover, litter biomass and understory vegetation

*Boutheina ADILI[1,*], Mohamed Hédi EL AOUNI[1], Salah GARCHI[2], Philippe BALANDIER[3,4]*

[1] Faculty of Sciences of Bizerte, Zarzouna, 7021, Tunisie, pinpignonbathboutha@yahoo.fr
[2] INRGREF, B,P. Ariana 2080 - Tunisie
[3] Cemagref, UR EFNO, Nogent-sur-Vernisson, France
[4] INRA, UMR547 PIAF, F-63100 Clermont-Ferrand, France

**Key words**
Regeneration, litter, pine, light, vegetation competition

## Introduction

Due to its ecological, aesthetic and economic values and its ability to withstand low intensity fires, the stone pine (*Pinus pinea* L.) is one of the most valuable species used in Tunisia for reforestation (Sghaier et al. 2006). However, little is known about natural regeneration possibility and particularly how abiotic factors such as soil fertility, temperature, humidity and light and biotic factors such as litter, understory vegetation and herbivory affect the process. This species is shade-intolerant and hence needs light to correctly regenerate but to an extent that should be specified. The understory vegetation and the litter quantity, both also related to light availability, are also known to influence stone pine regeneration. A better understanding of these processes would consequently help forest managers to secure the stand regeneration. The objective of the study was to relate the occurrence of stone pine seedlings in relation to stand structure including canopy cover, litter and understory vegetation in two forests of North Tunisia.

## Materials and methods

The two forests, Mekna and Ouchtata, located on coastal dunes of Nefza-Tabarka, have been intensively afforested with stone pine in some parts for about 50 years. The climate is mediterranean. The soil has mostly a sandy texture. The stone pine is the only overstory species, whereas the most commonly occurring shrub species were *Juniperus oxycedrus* ssp., *Juniperus phoenicea*, *Quercus coccifera* and *Pistacia lentiscus*. There was also an herbaceous layer consisting of *Bellis annua*, *Briza maxima*, *Geranium Robertianum* and *Silene colora*. Thirty-seven rectangular (25 × 20 m) sample-plots were randomly selected. In each plot, the age, height, DBH and mean crown diameter (CD) were measured on five sample-trees, one near the centre and the others closest to the four corners of the plot. The total number of pine in each plot was also counted ($N_t$). Overstory canopy cover (C, %) was then calculated by:

$$C (\%) = PCA.N_t.100/500$$

Where PCA is the projected crown area derived from ($\pi CD^2/4$). The biomass of the different species of the understory and the needle litter was recorded in 8 square subplots ($0.25m^2$). The number and age of stone pine seedlings were also determined in each plot.

## Results

A bell-shaped unimodal curve was recorded for the number of stone pine seedlings ($N_s$) according to overstory canopy cover (C) with a peak for the class 43, 5 − 58% (p < 0, 0001, fig.1). Stand age had also a significant positive effect on $N_s$ (p < 0.003, fig. 2). C and stand

age was often linked with a decrease of C for young stand, explaining the decrease of $N_s$ for the first cover class (29 – 43.5%, fig. 1).
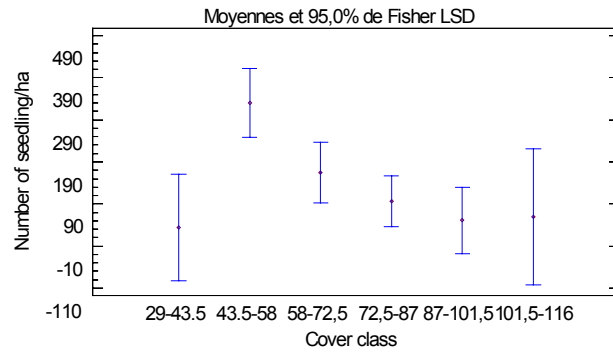


*Fig. 1. Number of* P.pinea *seedlings according to overstory cover (divided by classes of 14,5%) into forests of the coastal dunes of Nefza-Tabarka, Tunisia*
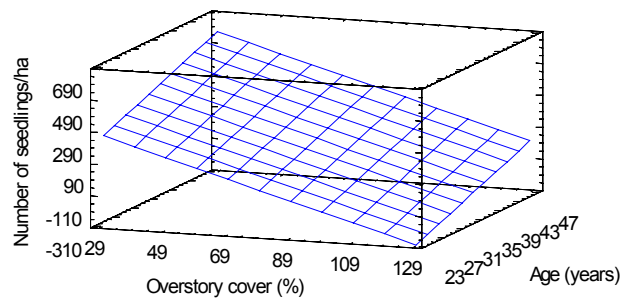


*Fig. 2. Number of* P.pinea *seedlings relative to overstory cover and stand age in two forests of the coastal dunes of Nefza-Tabarka, Tunisia.*

The litter quantity significantly decreased Ns ($N_s = (550–8.7*sqrt(Litter))^2$; $R^2 = 38\%$; p < 0.0001; fig. 3).
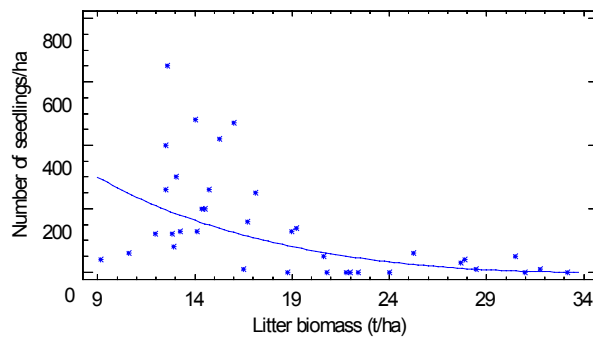


*Fig. 3. Relation between biomass of litter (t/ha$^{-1}$) and relative number of* P.pinea *seedlings in two forests of the coastal dunes of Nefza-Tabarka, Tunisia.*

The biomass of the understory vegetation (shrubs, grasses and forbs) had globally no significant effect on $N_s$ ($R^2 = 7.53\%$), whereas the p-values tended to show that grasses had the most negative impact (0.36, 0.2 and 0.63, for shrubs, grass and forbs, respectively).

Stone pine seedling age varied with C, with seedlings older than 2-year-old were recorded mostly for C < 72.5% (Fig. 4).
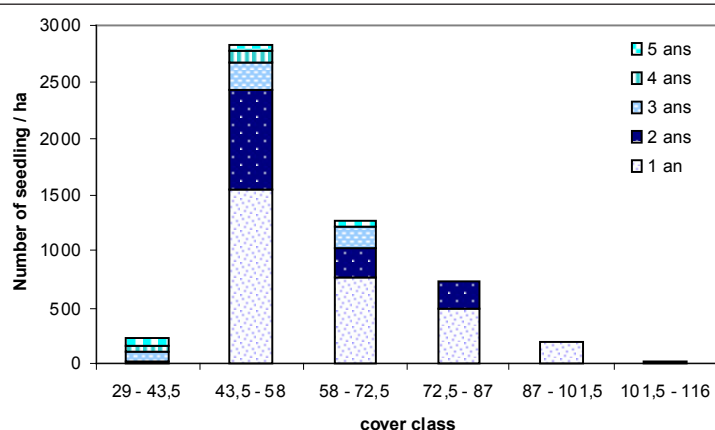


*Fig. 4. Distribution of the number and age of* P.pinea *seedlings according to the cover class in two forests of the coastal dunes of Nefza-Tabarka, Tunisia.*

**Discussion:**

Stone pine seedling number and age were negatively correlated with overstory canopy cover. Stand age favored $N_s$, probably through an increase of cone and seed production with tree age. A decrease of $N_s$ for the first class of cover is linked to the intrinsic structure of data, i.e. the stands with the lowest cover were also the youngest, and consequently with a low seed production.

Litter quantity had a negative effect on seedling recruitment and establishment, in accordance with the results of other studies (Bosy and Reader 1995; Facelli and Facelli 1993; Fowler 1988). Thus, litter may delay or abort seedling emergence either by preventing contact between seminal root and mineral soil, through mechanical restriction to hypocotyl elongation and emergence of cotyledons (Cacia and Ballaré 1998), or by chemical effects by dissolved litter substances (allelopathic effect) (Bosy and Reader, 1995). The understory vegetation did not seem to have a marked effect.

As a consequence, the effect of overstory canopy cover on seedling number and age would imply a light effect, i.e. an increase of them with light, but also a litter effect, which quantity increases with canopy cover. Both factors are difficult to separate and further controlled experiments are needed to specify their respective influence.

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# The role of understory vegetation in Mediterranean forestry in the view of global change

*Fernando Valladares*[1,2] *and Lluis Coll*[3]

[1]Instituto de Recursos Naturales. CCMA, CSIC, Serrano 115 dpdo. E-28006 Madrid, Spain
[2] Departamento de Biología y Geología, ESCET, Universidad Rey Juan Carlos, c/ Tulipan s/n Móstoles, E-28933 Madrid, Spain
[3] Centre Tecnologic Forestal de Catalunya. Ctra. San Llorencs de Morunys km 2 Solsona, E-25280 Lleida, Spain.

Climate change is bringing warmer and drier conditions to Mediterranean forests. But climate is not the only challenge faced by these ecosystems. Dramatic land-use changes involving habitat fragmentation and degradation, alterations in the intensity and frequency of fires, and introductions of exotic species are taking place at a rapid rate.

An unusual but ecologically relevant perspective on the impacts of global change in forest ecosystems can be obtained from looking at the understory and not at the canopy. Most plant species spend at least part of their life in the understory and many key ecological and biogeochemical processes take place in the understory. Shade and improved soil conditions under the canopy facilitate establishment of plants. However, this facilitation can vanish under very harsh conditions. Globally changing environmental drivers can profoundly modify the cost-benefit balance of life in the understory, but sound modelling of ecosystem dynamics and the impacts of global change is currently impaired by our reductionistic approach to understory life. Forest understories play a crucial role in the regeneration of many woody species, but land abandonment coupled with a changing climate is making them drier and more prone to catastrophic fires due to an increased accumulation of fuel. Understanding understory ecology in a holistic way can have profound implications for the conservation and adaptive management of Mediterranean forests under global change.

# Light-mediated influence of three understorey species (*Calluna vulgaris, Pteridium aquilinum, Molinia caerulea*) on growth and morphology of *Pinus sylvestris* seedlings

*Noémie Gaudio[1], Philippe Balandier[1, 2], Gwenael Philippe[1], Yann Dumas[1], Frédéric Jean[1], Christian Ginisty[1].*

1) Cemagref, Research Unit on Forest Ecosystems
Domaine des Barres, F-45290 Nogent-sur-Vernisson, France
noemie.gaudio@cemagref.fr
2) INRA, UMR547 PIAF
F-63100 Clermont-Ferrand, France

**Key words**
Regeneration, competition, light, Scots pine, vegetation type

## Introduction

*Pinus sylvestris* is a light-requiring pioneer species. Therefore, its natural regeneration may be jeopardized by some forest understorey species that can intercept a significant amount of light depending on their development, which is also affected by light availability (Balandier et al. 2006, Gaudio et al. 2008). Although the negative effect of underground competition for resources was often highlighted (Nambiar and Sands 1993), the literature does not offer much information on the growth response of Scots pine seedlings to different kinds of vegetation relative to light. The study focused on three common understorey species in acid temperate forests: *Calluna vulgaris*, *Pteridium aquilinum* and *Molinia caerulea.* Our objectives were (i) to quantify their impact on light quantity and quality according to their density, (ii) to record pine seedlings growth and morphology accordingly, and (iii) to compare the interactive effects of those three species. Our assumptions were that *Pteridium* has the worst impact on both light quality and quantity and, therefore, on pine seedlings growth and morphology, followed by *Molinia* and then by *Calluna*.

## Materials and methods

An experiment that mimics early competition of weeds and pine seedlings in a forest gap was set up in a nursery in spring 2007. Two factors were studied: the understorey species (*Calluna* C, *Pteridium* P and *Molinia* M) crossed with the density at planting (0, 10, 16, 33, 57 young individuals harvested in forest per m²) defining 15 modalities replicated in three complete blocks. In each of the resulting 45 plots (2 m² large), 50 pine seedlings (2 week-old) were planted at 20 cm intervals among the vegetation.

Vegetation development (height and cover, i.e. percentage of the ground area occupied par the vertical projection of the foliage), pine growth (diameter, height and leaf mass area) and light quantity (PAR, 400-700 nm) and quality (Red: Far Red ratio, R:FR, 660:730 nm) were measured in 2007 and 2008.

The data were analysed by variance analyses and simple regressions using Statgraphics software.
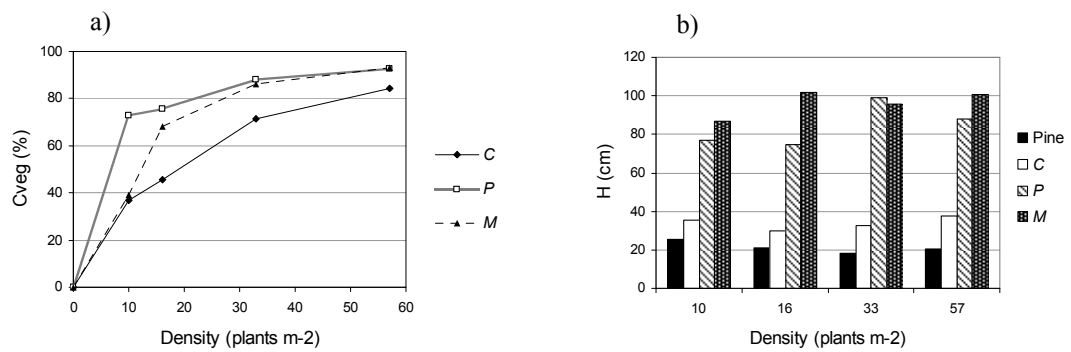
*Figure 1: Vegetation cover (Cveg) (a) and vegetation and pine height (H) (b) according to density of C, P and M.*

## Results and discussion

Cover of C, P and M increased logarithmically with density, with a higher increase for P and M than for C (Fig. 1a). Vegetation height did not vary with density, P and M being higher than C that had approximately the same height as pine seedlings (Fig. 1b).

At both highest vegetation densities, the light available at pine seedlings apex was reduced by 60% under P and M (Fig. 2) whereas there was no statistical difference among densities for C.
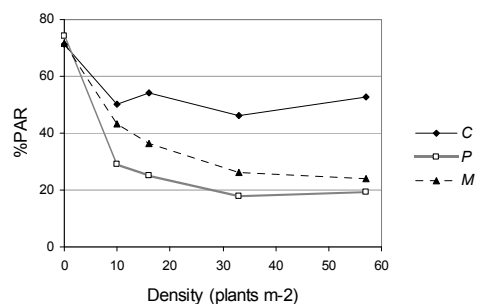


*Figure 2: Light quantity (%PAR) available at the pine seedlings apex according to density of the three species in the second year.*

Regarding light quality, R:FR was significantly reduced only under P cover (1.20 and 0.14 for densities 0 and 57 plants m$^{-2}$, respectively).

The increase in vegetation density caused a decrease in pine seedlings diameter (p<0.0001, $R^2$=56%) without any pronounced effect on seedling height. As a result, the height / diameter stem ratio (H/D) increased with vegetation density. However, year and species effects were observed (Fig. 3). In 2007, pine seedlings in P had the highest H/D and those in C the lowest one. In the second year, H/D slightly increased or remained stable in C and M whereas it significantly decreased in P (Fig. 3c).

Leaf mass on an area basis (LMA) has been reported as a functional trait of acclimation to light in the sense that shaded plants tend to increase their light interception area per biomass unit (King 2003). In accordance with measured light, such an effect was recorded in this experiment with a decrease of pine LMA with increasing vegetation density (p<0.0001, $R^2$=68%, Fig. 4). For all the densities, LMA was systematically higher for seedlings growing in C than in P and M. At low densities, LMA was higher beneath M than beneath P whereas it was the contrary for the highest density (p=0.0204) where pine needles were thinner (p=0.007) and lighter (p=0.0008) beneath M. This effect could be attributed to competition for underground resources, *i.e.* water and/or nutrients, in addition to light (Provendier and Balandier 2008).
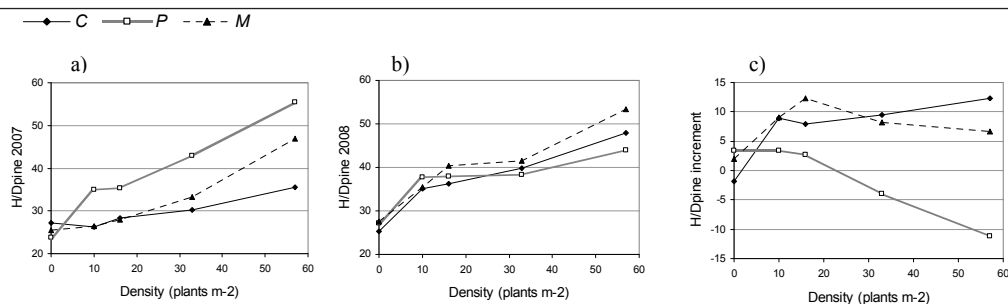
*Figure 3: Height/diameter stem ratio (H/Dpine) in 2007 (a) and 2008 (b) and H/Dpine increment (c) according to density of C, P and M.*
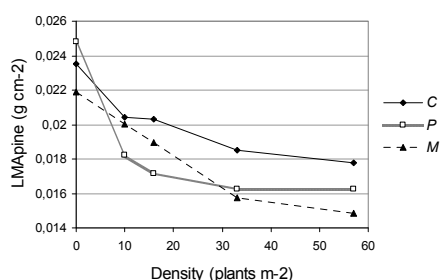


*Figure 4: Leaf mass on an area basis (LMApine) of the pine seedlings according to density of C, P and M.*

## Conclusion

P reduced the quantity of light available for pine and modified the light quality whereas C that was characterized by the same height as pine seedlings had only a limited impact. M greatly decreased light available for pine seedlings, whereas it had no effect on light quality. This result came probably from floral stalks that represent two-third of plant height for a negligible contribution to photosynthesis (*i.e.* they intercepted light without modifying its quality) whereas the leaf tuft had nearly the same height than pine seedlings.

As a consequence, the three weeds affected the pine diameter but with a strong species effect. P strongly decreased the pine diameter growth in the first year and also height growth in the second year. The main effect of M and C was delayed to the second year, particularly for C. However, it is noteworthy that C had an impact on pine seedlings diameter growth without any pronounced effect on light availability. This result suggested that others factors than light are involved in the effect of C.

With a fast development of its aerial part and an important cover, P is the most competitive species for light. At high density, M also seems to play a role via belowground resources in addition to light. LMA is confirmed to be a functional treat accounting for the effects of competition between species.

In the light of these results, identifying the vegetation type and thus its effect on resource availability and then on seedlings growth and morphology seems to be a key factor to consider in order to improve forest vegetation management.

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# Methods for describing light capture by understorey weeds in temperate forests: consequences for tree regeneration

_Philippe Balandier[1,2], André Marquier[2], Noémie Gaudio[1], Léon Wehrlen[3], Eric Casella[4], Lluis Coll[5], Andrea Kiewitt[4], Ralph Harmer[4]_

1) Cemagref, Research Unit on Forest Ecosystems, F-45290 Nogent-sur-Vernisson, France
Philippe.balandier@cemagref.fr
2) INRA, UMR547 PIAF, Clermont-Ferrand, France
3) INRA, UMR1092 LERFOB, MGVF, Champenoux, France
4) Forest Research, Alice Holt Lodge, Farnham, UK
5) CTFC, Solsona, Spain.

## Introduction

The amount of light reaching the forest understorey is one of the main environmental factors controlling the success of seed germination, seedling establishment and growth of trees in temperate forests. Forest operations like thinning lead to an increase of light availability that promotes the development of the ground vegetation, graminoids, forbs and shrubs, which may affect tree regeneration (Balandier et al. 2006). These plants can intercept a significant fraction of the available light in the understorey and the resulting light available for tree seedlings can vary greatly, depending on species identity and abundance in the ground flora. Although quantifying competition for light between species is of great interest to forest managers, assessing light capture by vegetation having such a complex structure still faces many technical challenges.

## Direct light measurement by sensors

Many sources of variability are combined and contribute to the very patchy structure of light under the different forest strata, these include: variability in space and time due to the structure and seasonal growth of the forest overstorey, variability due the understorey species phenology and development, and of course ecological site conditions (Fig. 1). Consequently many light sensors are needed to describe those heterogeneous systems which is a time consuming and expensive process.

## Indirect light measurement by hemispherical photographs

Hemispherical photographs could be more convenient to characterize light interception under different species (Fig. 2), but the method has drawbacks that are similar to hemispherical photographs used for assessing the overstorey (Balandier et al., 2009). These are the need to
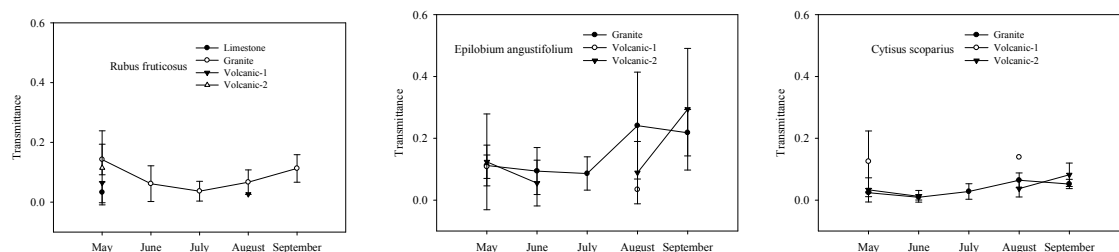


Figure 1: Seasonal evolution in 2005 of transmittance (light measured under the canopy divided by light measured above the canopy) measured at soil level with a linear PAR sensor 0.8-m long (Decagon device) under three colonizers of gaps in temperate forests, on different sites and soil substrates, Auvergne, France.

have a well contrasted photograph with no over-exposure and the subsequent difficulty in classifying pixels in sky or vegetation. For plants in the understorey an additional difficulty is that it is difficult getting a sharp image for both the understorey and the overstorey vegetation.
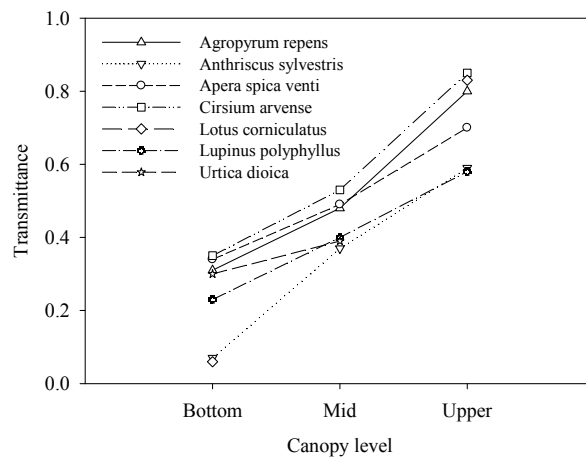


*Figure 2: Estimated values in light transmittance within contrasting canopy vegetation in an open field near Rostock, Germany. Measurements were recorded with a CI-110 hemispherical lens (CID Inc., USA).*

### Indirect light assessment by plant reconstruction and modelling

Mathematical methods dealing with plant architecture are being developed to model light capture by a range of plants including tree seedlings in contrasting understorey situations. Whilst many models have dealt with light transmission through forest overstorey the understorey vegetation is rarely considered (Lieffers et al. 1999). Among the different possibilities, two main approaches are generally considered, firstly an analogy with the physics of turbid media and secondly the use of plant mock-up and image computation.

The Beer-Lambert law of light extinction in a turbid medium has been used considering the leaves divided in infinitely small particles. Canopy architecture can be described as a grid of 2D or 3D voxels resulting from a spatial discretisation of the space occupied by the canopy (Fig. 4). Leaf area density in a voxel is assumed to be uniformly and randomly distributed, so that Beer's law is used at the voxel scale. However a true canopy is sometimes far from this theoretical assumption and different solutions have been proposed to account for a non-uniform leaf distribution in space (i.e., leaf clumping, Varlet-Grancher et al. 1993).
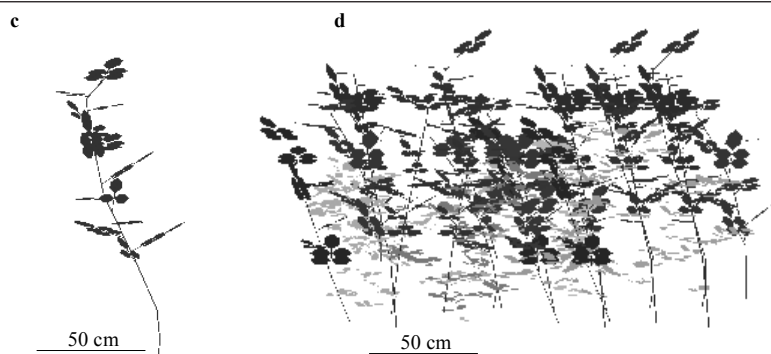


*Fig. 3: Examples of plant mock-ups used to compute light sharing between raspberry (Rubus idaeus) and beech (Fagus sylvatica) seedlings. Lateral view of isolated raspberry and lateral view of a scene with 6 beech seedlings (in grey) 50 cm from each other with a systematic network of raspberry (in black) between beeches, i.e. a raspberry plant every 50 cm.*

Plant mock-ups can also be used to calculate light interception by image processing. The principle is often to project the image of the mock-up in a given direction as viewed by a camera. Then the ratio between the projected area by the total leaf area of the plant (STAR, Silhouette to Total leaf Area Ratio) is an estimation of light interception efficiency in a given direction. This STAR value multiplied by the incident light amount above the canopy in the same direction gives the amount of light which is intercepted or transmitted by the plant. It can be integrated on different sun directions to account for a daily sun path or the whole sky hemisphere. If different colours are used, the STAR can be calculated only for pixels with a given colour (projected area for a given colour) and hence different plants can be distinguished as well as light sharing between them (Fig. 3, 4). Three-dimension plant digitising to build mock-ups is very time consuming and consequently cannot be used extensively. However fig. 4 shows that the turbid medium approach can lead to acceptable results, particularly for dense or continuous understorey cover (*i.e.* a low value of STAR).
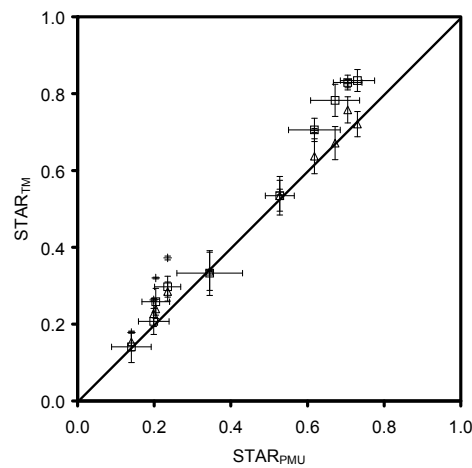


*Fig. 4: Comparison of the STAR value of beech seedlings in association with raspberry computed from images (fig. 3) of plant mock-ups ($STAR_{PMU}$) and from turbid medium simulations ($STAR_{TM}$): square: 1D turbid medium model; cross: two-layer model; triangle: 3D turbid medium model. (Mean and standard-deviation computed on 6 seedlings).*

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# Can plantations develop understory biological and physical attributes of naturally regenerated forests?

*Christian Messier[2], Isabelle Aubin[1] and André Bouchard[1]*

[1]Inst. de recherche en biologie végétale (IRBV), CEF, Université de Montréal, 4101 rue Sherbrooke Est, Montréal, Canada, H1X2B2, iaubin@sympatico.ca
[2]Centre d'Étude de la Forêt (CEF), Dép. Sci. Biol., Université du Québec à Montréal, C.P. 8888, Succ. Centre-Ville, Montréal, Canada, H3C3P8, messier.christian@uqam.ca

**Key words**
Ecological integrity, restoration, plant functional types, understory flora

## Introduction

Around 60 000 km² of primary forest are lost or modified annually by human interventions around the globe (FAO, 2007). In many regions, this marked loss of natural forests has been offset by the rapid increase in forested lands allocated to plantations (FAO, 2007). While plantations provide tree cover and forest wood products, little is known about their potential to fulfill other ecological services typical of the ecosystems that they are replacing, such as the maintenance of biodiversity. This study aimed at evaluating to what extent plantations can be compared to naturally forests. To characterize the functionality of forest ecosystems, we used understory community, in terms of its functional and structural attributes, as an indicator of the ecological integrity of the whole ecosystem. The understory flora is a suitable key element to evaluate ecological integrity of an ecosystem because of its high compositional, structural and functional diversity, its numerous interactions with different trophic levels, and its important role in ecosystem functioning (Nilsson and Wardle, 2005).

## Materials and methods

Fifty-six plots were established within two areas of deciduous forest in the Great Lakes-St. Lawrence forest region of southern Quebec, Canada (around Montréal). Naturally established, mature mesic forests in both regions are normally dominated by *Acer saccharum* in association with *Fagus grandifolia*, *Tilia Americana*, *Ostrya virginiana* and in some places, *Carya cordiformis*. Fourteen polyculture deciduous (DP) and 18 monoculture conifer (CP) plantations were surveyed. They were compared with 24 naturally regenerated stands of an old field-deciduous forest succession of pasture origin, hereafter referred to as unplanted stands (UN) and six old naturally-regenerated forests (NAT). Stands from these three stand types were classified according to their stand stages: (O) open canopy, age 7 – 25 years, maximum tree height 3 – 8 m; (C) closed canopy, age 14 – 39 years, maximum tree height 8 – 17 m, complete canopy closure but immature stem; (M) mature canopy, 32 – 65 years, maximum tree height 14 – 24 m, economically mature stem.

Within each plot, 52 circular points (15-cm radius) were systematically sampled along four 25-m transects. The frequency of occurrence (%) of a given species was the proportion of points within a plot where that species occurred. All woody species with a DBH (diameter basal height) < 5 cm and a height < 5 m were included. Planted tree occurrences were recorded separately. To describe vertical structure, we sampled the vegetation as described above for every 50 cm in height, from the soil surface to the top of the understory vegetion. Vertical light attenuation was also measured.

Information on species ecological traits was obtained from the TOPIQ data base (Traits Of Plants In Quebec, see Aubin et al., 2007). Ten categorical and two quantitative traits were used in the present study (Data not shown). Emergent groups (i.e., groups of species having similar biological traits) were identified separately for woody and herbaceous species. We examined the relative occurrence of these groups between stand types and among the different stand stages. Understory vegetation assemblages were compared using principal components analysis (PCA) on the matrix of the relative occurrences of emergent groups.

### Results

A total of 84 woody species and 269 herbaceous species were recorded. Cluster analysis delineated six emergent groups for the woody species and nine for the herbaceous species. As grasses and sedges were not identified to species, they were assigned to an a priori group.

The two PCA axes of the species groups relative occurrence illustrated the distribution of emergent groups among the different study plots (n = 56, Figure 1). The first principal component (F1) represented mostly a gradient of deciduous stand development, with open canopy stages (O) on the left and mature canopy (M) and old naturally regenerated forest stands (NAT) on the right sides of the ordination. This successional gradient was reflected in the location of the emergent groups in the ordination biplot; pioneer species groups that were associated with open habitats (H1 to H5, and grass) were on the left-hand side of axis F1, while spring-flowering ant-dispersed herbs (H9) and woody species (W) associated with mature and old naturally regenerated stands were on the right. Conifer plantations (CP) tended to segregate from other stand types along the second axis (F2). Ferns and spring-flowering herbs that were dispersed by mammals or birds (H7), or by wind and gravity (H8),
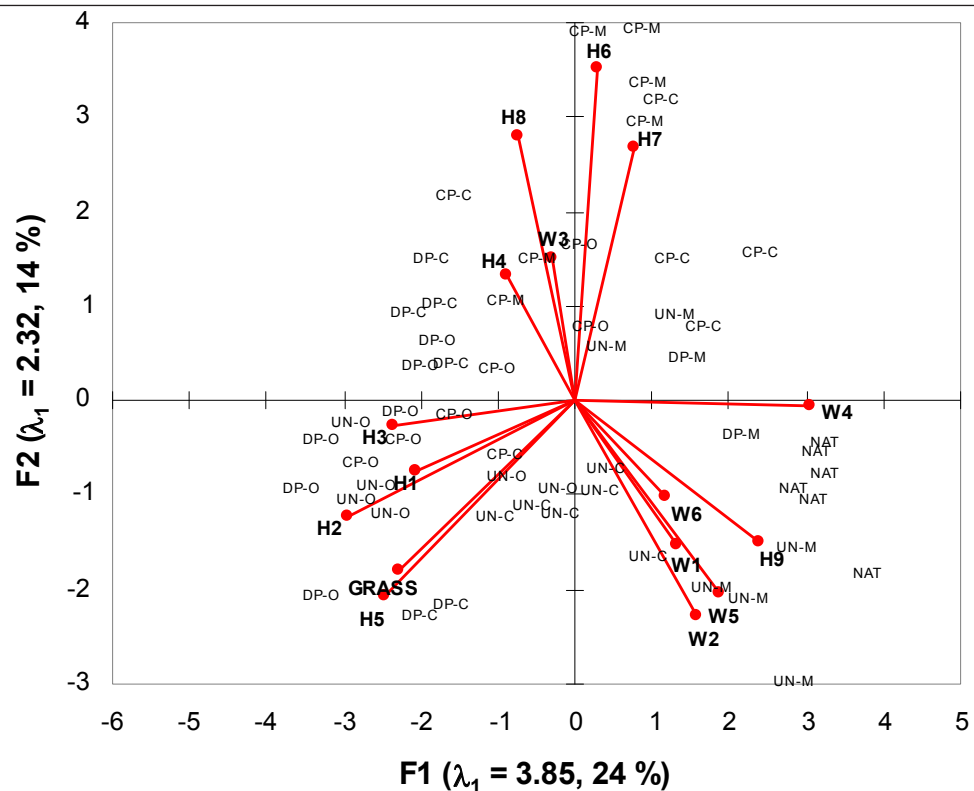


*Fig. 1– PCA calculated on the emergent group relative occurrence matrix. Nat: old naturally regenerated; UN-M: unplanted mature; UN-C: unplanted closed; UN-O: unplanted open; DP-M: mature deciduous plantation; DP-C: closed canopy deciduous plantation; DP-O: open canopy deciduous plantation; CP-M: mature conifer plantation; CP-C: closed canopy conifer plantation, CP-O: open canopy conifer plantation.*

were located at the top of axis F2, while woody species (W) and late-flowering herbs (H5) were at the bottom. Old naturally regenerated forest stands (NAT, n = 6) formed a tight, homogeneous grouping on the right inside of the plot.

Vertical stratification and light distribution also varied among stand types and stages (data not shown).

## Discussion

Clear patterns in species trait responses were found along stand developmental stages. Light-demanding and wind-dispersed species groups, such as grasses, exotics and summer- or late summer-flowering herbs, were predominant in open canopy stands. Conversely, woody groups and ant-dispersed spring flowering herbs were associated with mature canopy stands and old naturally regenerated forests. We noted clear contrasting differences in understory development between coniferous and deciduous plantations. At young stages, the understory assemblages and understory environmental conditions were quite similar between the two plantation types, but radically different in mature canopy stands. Understory attributes were much more similar to old naturally regenerated forests in the deciduous plantations compared to the coniferous ones.

This study demonstrates that deciduous plantations can develop, over time, functionally similar understory native flora as old naturally regenerated northern hardwood forests. However, conifer plantations showed a completely different pathway of understory development.

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# Vegetation management and sustainable management of mixedwood stands in western Canada's boreal forest

*Philip G. Comeau*

University of Alberta, Dept. of Renewable Resources, 751 General Services Building, Edmonton, Alberta, Canada T6G 2H1; Telephone: 780-492-1879; FAX: 780-492-2343; Email: Phil.Comeau@UAlberta.ca

**Abstract**

Mixedwood stands are widespread in the boreal forests of north America and represent approximately 70% of the upland forest area in northwestern Canada. These stands are dominated by trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) with minor components of other species. A herbaceous layer, dominated by bluejoint reedgrass (*Calamagrostis canadensis*) (a sod forming perennial grass) is also an important component of these ecosystems. Following stand replacing disturbances (such as fire or harvesting), aspen can regenerate in abundance and due to its superior height growth it dominates the canopy for 60 years or longer, until spruce grows up into the canopy. Over time stands succeed from pure aspen stands (with a spruce understory) to aspen dominated mixtures, then spruce dominated mixtures, and ultimately (over a long period without disturbance) to spruce dominated stands. Both aspen and herbs compete with spruce during early stages of development. Cold wet soils and frost injury also present problems for spruce regeneration on some sites. Aspen canopies reduce both frost injury and levels of herbaceous competition and the impacts of white pine leader weevil (*Pissoides strobili*) on white spruce. Without site preparation and competition management it is likely to take 120 years or longer for spruce dominated mixedwood stands to develop. Since this is longer than typically accepted rotations, management is required in order to maintain the conifer dominated mixedwood cover class within a working forest. Costs for maintaining mixedwood stands are often higher for monocultures, and yield benefits of these mixtures are small and variable. In this presentation I will review current knowledge regarding competition and facilitation in this system. I will also discuss promising options including the use of mechanical site preparation, herbicides, motor-manual cutting, and successional management for creating and managing mixedwood stands in more cost-effective ways.

# Analysing shrub control patterns in Mediterranean forests by basic site and stand structural parameters

*Lluís Coll[1], José Ramón González Olabarria[1], Timo Pukkala[2], Christian Messier[3]*

[1] Centre Tecnològic Forestal de Catalunya, Ctra. St Llorenç, km 2, 25280, Solsona, Spain.
lluis.coll@ctfc.cat
[2] Faculty of Forest Sciences, University of Joensuu, FIN- 80101, Joensuu, Finland
[3] Centre d'Étude de la Forêt, UQAM, H3C 3P8 Canada, Montréal, Québec, Canada

## Introduction

The understory stratum plays key roles on the functioning of forest ecosystems. It provides food and habitat for the fauna (González-Hernández et al. 1998), protection from depredation or sun exposure to the regeneration (Kuiters and Slim 2003. Kunstler et al. 2007), competition for natural resources (Coll et al. 2003), and it constitutes a major component of forest biodiversity (Kerns and Ohmann 2004). Furthermore, in Spain, as in other Mediterranean countries, controlling the understory is essential not only to reduce competition to the regeneration, but also to prevent and reduce the occurrence of catastrophic fire events which are the main cause of forest lost (González and Pukkala 2007).

The ability to assess how stand structural parameters (e.g. density, basal area, stand height) determine the development of the understory is therefore of great interest to forest managers because stand attributes can be modulated through adequate silvicultural practices. However the above mentioned relationships remain unclear (e.g. Pyke and Zamora 1982, González-Hernández et al. 1998, but see Légaré et al. 2002) and there are still a lack of empirical studies examining them. In this study, we aim at analysing and modelling the relationship between basic and simple structural parameters such as stand basal area and shrub cover for the main tree species of Catalonia (north-east Spain). In addition, we evaluate the possible role played by stand elevation on this relationship.

## Materials and methods

*Study species and data preparation*

Data on forest stands were obtained from the third Spanish National Forest Inventory (NFI) in Catalonia region (north-east Spain). For our study, we selected those plots corresponding to forest stands in which one of the following species from the Pinaceae or Fagaceae fami-
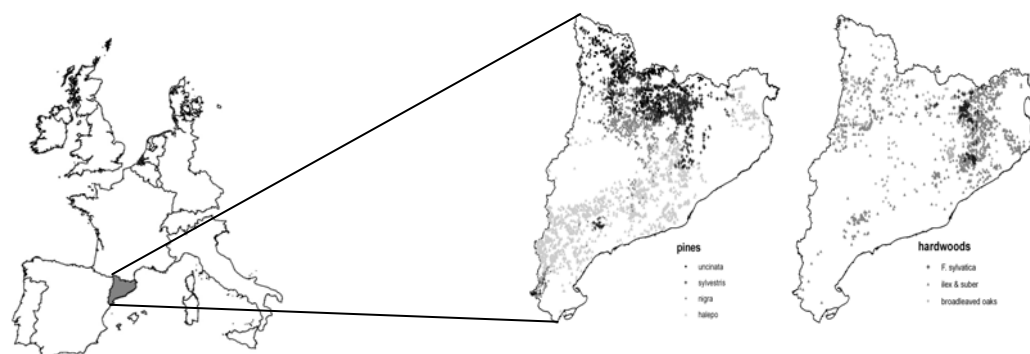


*Figure 1. Species distribution across Catalonia following NFI3 database.*

lies were dominant (i.e. occupy > 80% of total basal area): *Pinus halepensis*, *Pinus nigra*, *Pinus sylvestris*, *Pinus uncinata*, *Quercus ilex*, *Quercus humilis* and *Fagus sylvatica* (Figure 1).

In Catalonia these species are distributed following a climatic and altitudinal gradient, with *P. uncinata*, *P. sylvestris* and *F. sylvatica* being the ones located at higher altitudes (and rather mesic sites) and *P. halepensis* and *Q. ilex* being distributed in lower altitudes in sites submitted to moderate to high summer drought.

The following variables from the selected NFI plots were recorded: elevation (*Ele*, m.a.s.l.), tree density (trees ha-1) and shrub cover (*SCov*, %). stand basal area (*G*, m2 ha-1) was calculated for each plot from the diameter and the sampled surface (Table 1).

*Table 1. Description of the main characteristics of the NFI plots used in this study (mean, standard deviation)*

| Species | Plots (n) | Elevation (m.a.s.l.) | | Density (trees ha-1) | | Basal area (m2 ha-1) | | Shrub cover, (%) | |
|---|---|---|---|---|---|---|---|---|---|
| *P. sylvestris* | 966 | 11.6 | ±3.5 | 753.2 | ±501.2 | 22.1 | ±11.5 | 33.1 | ±28.8 |
| *P. uncinata* | 370 | 18.9 | ±1.8 | 728.7 | ±530.2 | 24.8 | ±13.4 | 29.1 | ±33.7 |
| *P. halepensis* | 1273 | 3.7 | ±1.8 | 491.2 | ±402.8 | 11.8 | ±8.4 | 82.3 | ±38.2 |
| *P. nigra* | 506 | 6.9 | ±2.1 | 845.2 | ±583.0 | 17.7 | ±10.3 | 47.5 | ±30.8 |
| *Q. humilis* | 154 | 8.4 | ±2.8 | 746.6 | ±606.0 | 12.9 | ±8.9 | 38.7 | ±31.1 |
| *Q. ilex* | 683 | 6.7 | ±2.8 | 1149.6 | ±796.4 | 14.2 | ±9.3 | 62.4 | ±43.2 |
| *F. sylvatica* | 125 | 10.8 | ±2.4 | 796.9 | ±478.9 | 24.9 | ±9.5 | 21.8 | ±27.9 |
| All | 4344 | 8.1 | ±5.2 | 744.4 | ±592.5 | 16.9 | ±11.2 | 55.2 | ±41.4 |

*Statistical analyses and modelling*

We used a non-parametric Kruskall-Wallis test to assess for differences in *Scov* stands of different species. Maximum response models were built to restrict variation induced by other factors and to quantify the limit at which the understory is controlled by both *G* and *Ele*. For this analysis, plots were divided following their basal area in 100 parts and, for each part, one third presenting higher shrub cover values were selected for the model. A multiple regression analysis was then performed for each canopy species, relating *Scov* with *G* and associated *Ele*, using SPSS software.
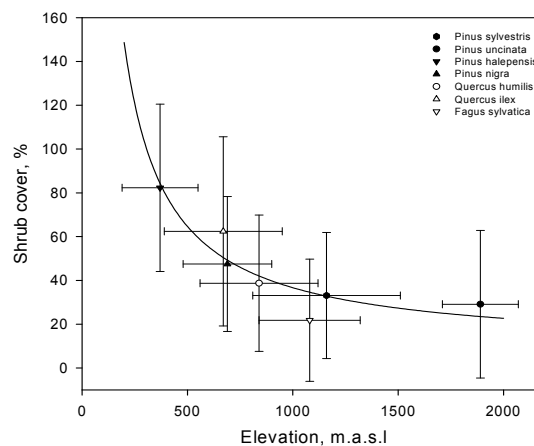


*Figure 2. Relationship among stand elevation and shrub cover (all species and plots)*

*Several factors could explain this pattern: First, drought-tolerant species present, in general, low leaf area indices (Gholz 1982) and, as a consequence, higher light transmission through their canopies than more mesic stands, thus favouring understory development. Furthermore, P. halepensis and Q. ilex forests present, in general, smaller basal areas (< 15 m2 ha-1) than the remaining species, hence forming open woodlands that allow the shrub layer to develop. The generally low livestock pressure found in these forest types help explain, in part, these results.*

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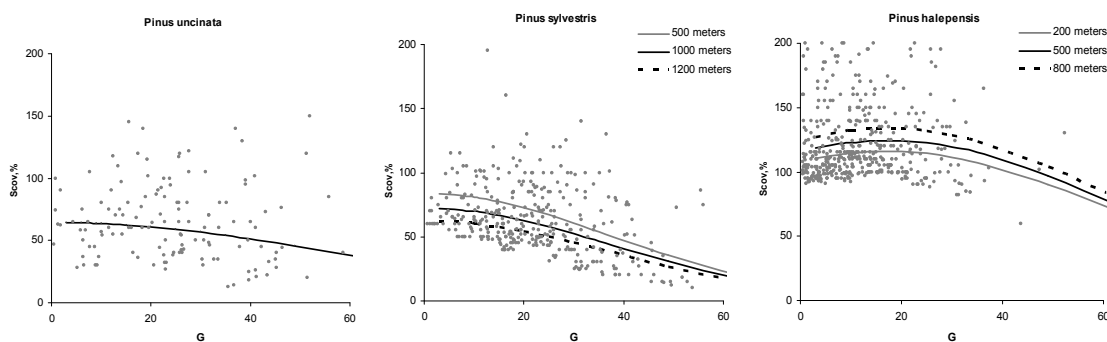
*Figure 3. Multiple regression models relating basal area (G, m2 ha-1) and shrub cover for different stand elevations*

## Results and discussion

### Elevation effect at regional level

Mean shrub cover was rather variable within each stand type and ranged between 21.8 to 82.3%, the later corresponding to *P. halepensis* stands and the former to those dominated by *F. sylvatica*. The mean *Scov* for the remaining overstory species was lower than 50% (although fairly variable) with the exception of Holm oak (62.4%). *Scov* was found to be inversely correlated with *Ele* (R2 = 0.86) when all species were put together in the model (Figure 2).

### Elevation and structural effect at species level

Maximum response models reflected a significant negative effect of basal area (G) on shrub cover for all species with the exception of *Q. ilex* stands (Figure 3). For a given basal area, a significant positive effect of *Ele* on *Scov* was found for stands of *P. sylvestris*, *P. nigra* and *Q. ilex* (thus following the pattern found at the regional scale) but an opposite trend was observed in stands of *P. halepensis*. In contrast, *Ele* was not correlated with *Scov* for stands of *F. sylvatica*, *Q. humilis* and *P. uncinata*, indicating that such relationships are highly species specific.

Multiple regression models relating *SCov* with *G* and *Ele* fit well for the species located in intermediate altitudes growing without severe limiting conditions (*Pinus nigra*, *Pinus sylvestris*, *Quercus humilis* and *Fagus sylvatica*). In contrast, regression models were not able to explain a significant proportion of the *SCov* variance for those stands belonging to the species distributed at the extremes of the altitudinal gradient. In those cases, the effect of the overstory on understory development is probably override by other factors such as topography and microsite variability (i.e. Gracia et al. 2007**)**

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# Biological sprout control of birch (*Betula* spp.) with the decay fungus *Chondrostereum purpureum* in Finland

*Henna Vartiamäki* [1]*, Jarkko Hantula* [1]*, Antti Uotila* [2]*, Pekka Maijala* [3]

1) Finnish Forest Research Institute, Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa, Finland
henna.vartiamaki@metla.fi
2) University of Helsinki, Hyytiälä Forestry Field Station, Hyytiäläntie 124, , FI-35500 Korkeakoski, Finland
3) University of Helsinki, Department of Applied Chemistry and Microbiology. P.O. Box 56, FI-00014 University of Helsinki. Finland

**Key words**
Vegetation management, mycoherbicides, biocontrol, *Chondrostereum purpureum*

## Introduction

Sprouting of fast-growing broad-leaved trees causes problems in newly planted and young coniferous stands, under power transmission lines, and at roadsides and railways. The modern use of chemical herbicides has been discarded due to their harmful impact to the environment, and the most common method to prevent sprouting is mechanical cutting. However, mechanical cutting alone is an ineffective control method for many broad-leaved species, because usually they quickly resprout after cutting. Thus, development of new alternative and more efficient methods for sprout control is a continuing challenge.

Researchers in the Netherlands and in Canada have demonstrated the potential of the white-rot fungus, *Chondrostereum purpureum* (Pers. ex. Fr.) Pouzar, for successfully controlling stump sprouting of many broad-leaved trees (Scheepens and Hoogerbrugge 1989, Wall 1990, Wall 1991, Dumas et al. 1997, Harper et al. 1999, Pitt et al. 1999, De Jong 2000). In practice, sprout control is conducted by placing fungal mycelium on freshly cut stumps immediately after cuttings. In Canada, there are already two registered *C. purpureum* products for biological sprout control in market. However, the use of those products in the other continents is questionable, because of uncertainties about their action in the new environment. Although *C. purpureum* possesses a worldwide distribution and is a very common fungus also in Finland, using a native fungus for biological control is preferred as a safe alternative.

The primary aim of the present study was to determine the potential use of the native isolates of *C. purpureum* as an inhibitor of stump sprouting in birch in Finland. We studied the effect of application time on the efficacy of *C. purpureum* treatment to prevent sprouting and tested if the efficiency of various isolates differed in preventing sprouting. We also clarified the mode of action of the fungus when preventing stump sprouting. The aim was also to determine the potential environmental risks in using *C. purpureum* as a biocontrol agent.

## Materials and methods

Birches were chosen for this study as experimental tree species because most of the broad-leaved trees growing in Finland belong to the genus *Betula*.

Field trials were established to study the effect of application time on the efficacy of *C. purpureum* treatment. Applications were conducted on 12 dates, between May 2 and October 12 in 2005, 2-week intervals. The birches were manually cut with the brush saw and the entire

surface of the cut stem was treated with inoculum of *C. purpureum*. Control stumps were left untreated or they were treated with blank inoculum. Plots were examined one and two years after the treatments and the number of living sprouts per stump was counted and the height of the tallest living sprout was measured. Data were analyzed with two-factorial analyses of variance and significant differences were tested by using Tukey's post hoc test.

A total of eight different isolates of *C. purpureum* were tested in the field trial to compare if the efficiency of various isolates differed in preventing sprouting. Isolates were selected for the field trials based on the laboratory tests, where enzymatic activities and mycelium biomass production of the isolates were tested. In the field, a total of 40 treatment plots were established, consisting of four replicates of each treatment (*C. purpureum* treatment and two types of controls). The plots were examined one and two growing seasons after treatments and the number of living sprouts per stump was counted and the height of the tallest living sprout was measured. Data were analyzed with ANOVA and Duncan multiple range test.

To evaluate the potential environmental risks of using *C. purpureum* as a biocontrol agent, the genetic diversity of *C. purpureum* in Nordic and Baltic countries was studied using random amplified microsatellite (RAMS) markers. The study included 85 different isolates from five different populations (four from Finland and one from Lithuania) and three different primers were used for analyses.

**Results and discussion**

The effect of the *C. purpureum* treatment was greatest when it was conducted in May, June or July and less effective towards the end of the growing season (Vartiamäki et al. 2009). For example, when the treatment was conducted in mid-July, only 13% of treated stumps showed resprouting two years after treatment, compared with 74% of control stumps. When the treatment was done in late summer, the effect of the treatment improved during the second year, indicating that control of stump sprouting with *C. purpureum* is a slow-acting process. Treatment conducted in late autumn (late September–October) did not differ from the controls. Treatment had no effect on the maximum height of the tallest living sprouts in any of the treatment times tested.

There were clear differences between single *C. purpureum* isolates in preventing sprouting of birch (Vartiamäki et al. 2008a). Three of the eight isolates tested were clearly more effective to prevent sprouting than others. Interestingly, it seemed that isolates that possessed high oxidative activities in the laboratory seemed to inhibit sprouting most efficiently in the field. However, further analyses should be conducted to confirm this connection.

The genetic diversity of *C. purpureum* in Nordic and Baltic populations showed to be high, but almost a complete lack of local differentiation existed. The results implies that distributing any local genotype of this fungus as a biocontrol agent should not lead to introduction of novel genes or genotypes in studied area, and the use of any native genotype as biocontrol agent should therefore be safe (Vartiamäki et al. 2008b).

The results showed that *C. purpureum* is a promising biological sprout control method in birch in Finland. It would also be useful to test the effectiveness of native isolates of *C. purpureum* on broad-leaved trees other than birch. The searching for more efficient isolates for future biocontrol purposes will also assume increasing importance, since the results showed that various isolates differed from each other in their capability in preventing sprouting.

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# Phytotoxicity of herbicides to container Norway spruce seedlings

_Marja A. Poteri[1] and Eevamaria Harala[1]_

[1] Finnish Forest Research Institute, Suonenjoki Unit, Juntintie 154, FI-77600 Suonenjoki, Finland
marja.poteri@metla.fi

**Key words**
nursery, weed management, herbicide, container seedling

## Introduction
The majority of the forest tree seedlings grown in the Nordic Countries are produced in hard plastic containers, in cell trays, with each seedling forming its own 'pot'. Pure _Sphagnum_ peat is used as the growth medium. Seeds are germinated in plastic greenhouses and after 4-8 weeks the containers are moved to outdoor gravel areas where seedlings will harden before delivery.

Controlling weeds is one of the main obstacles in producing container conifer seedlings economically. Emerging conifers are relative slow in the initial stage of their development and leave growth space for competing weeds. Mini-seedlings transplanted into bigger pot also have a slower shoot growth phase after transplanting and in outdoor field conditions the open space in containers is easily exposed to wind-carried seeds.

Systematic data on weeds occurring in Nordic forest nurseries raising container stock is very scarce. Most harmful weeds belong mainly to wind-dispersed species such as _Epilobium_ spp., _Betula_ spp., and _Salix_ spp. In Finland, intensive container production has been on-going for some 20 years and during this time _Rorippa_ spp., _Sagina_ spp., and _Gnaphalium_ spp. have become more common. Occasionally, some peat-related species, e.g. _Carex_ spp., _Bidens tripartita_ and _Ranunculus sceleratus,_ may also occur. A minor proportion of weeds have been gramineous species, such as _Poa annua_ and _Agropyron_ spp.

This paper summarizes some results from a series of phytotoxicity trials with herbicides applied to container Norway spruce seedlings.

Table 1. Herbicide treatments in the experiments with container spruce seedlings.

| Application date, place and used herbicide | Active ingredient and dose, kg ha-1 | Growth stage of spruce seedlings at time of application |
|---|---|---|
| 29.6.2005, outdoor field Goltix 700 SC, 700 g/l Kerb 500 SC, 500 g/l | metamitron: 1.4, 4.2 propyzamide: 1.9, 2.5 | 1-year-old in active growth, pot-to-pot transplanted in May 2005 |
| 14.6.2006, outdoor field Goltix 700 SC, 700 g/l Kerb 500 SC, 500 g/l | metamitron: 1.4, 4.2 propyzamide: 1.9, 2.5 | 1-year-old in active growth, pot-to-pot transplanted in May 2006 |
| 8.8.2007, outdoor field Goltix 700 SC, 700 g/l Kerb 500 SC, 500 g/l Medifam 320 SC, 320 g/l | metamitron: 1.4 propyzamide: 1.9 phenmedipham: 0.26, 0.84 | 1-year-old in active growth, pot-to-pot transplanted in June 2007 |
| 29.5.2008, in plastic house Select, 240 g/l Focus Ultra, 100 g/l Agil 100 EC, 100 g/l | clethodim: 0.09, 0.19 cycloxydim: 0.2, 0.4 propaquizafop: 0.06, 0.12 | 6-week-old in active growth, sown in April 2008 |

## Materials and methods

Herbicide experiments were made with Norway spruce *Picea abies* (L.) Karst. seedlings, which were pot-to-pot transplanted or sown in Plantek® PL81 containers filled with pure *Sphagnum* peat. The growing density was 546 seedlings per sq. m and each pot had a size of 0.85 cm$^3$. The application time and the growth stages of the seedlings varied according to the year of the experiment (Table 1).

In the treatment, 3-9 containers (81 seedlings/container) were sprayed (200 l ha-1) using a test sprayer. After application, the containers were arranged in a completely randomized design and the seedlings were grown according to conventional nursery practices.

Seedling shoot growth after herbicide application was measured and growth disorders were recorded during the treatment year. In the following spring, possible abnormalities in shoot growth from terminal buds and Root Growth Capacity (RGC) of the overwintered seedlings were determined.

ANOVA analysis with appropriate transformations was used to analyse the data. The seedling height before application was used as a covariate for shoot growth.

## Results and discussion

With pot-to-pot transplanted seedlings, common growth abnormalities besides needle chlorosis and tip burning included stunted growth and shoot thickening during the treatment year. Twisting and branching of shoots also occurred.

In 2006, propyzamide and the higher dose of metamitron reduced the height growth of pot-to-pot transplanted spruce seedlings as compared to control seedlings, but phenmedipham had no effect on the growth of sown spruce seedlings in the late August treatment in 2007 (Fig. 1). In 2006, the application was earlier than in the experiments in 2005 and 2007. In 2008, graminicides were tested with sown seedlings in the plastic greenhouse and in this experiment clethodim, cycloxydim and propaquizafop did not affect shoot height growth (data not shown).

In the following spring, both propyzamide treatments and the higher metamitron dose tended to induce more multiple leaders than was the case among the control seedlings. The dry matter content of new roots was also reduced in these treatments. Phenmedipham had less
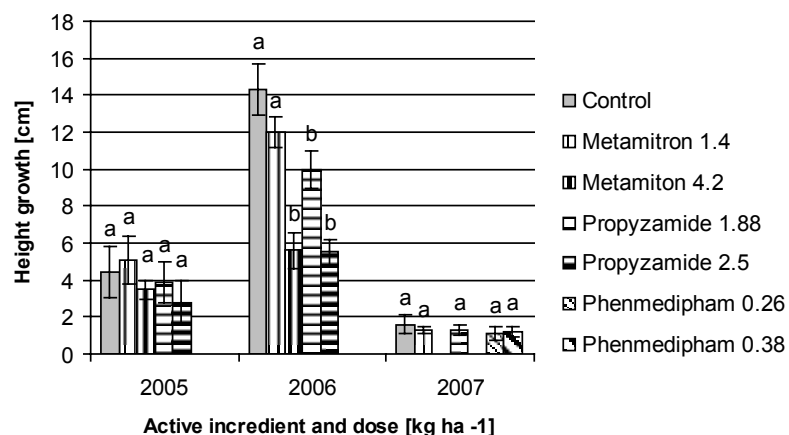


Fig. 1. Height growth of Norway spruce seedlings in the experiments 2005-2007.

negative effects on seedling condition. The phytotoxicity of graminicides was not monitored over the winter as they did not cause any symptoms during the growing season.

In pure peat, it is especially challenging to determine the balance between herbicide efficacy and phytotoxicity. Small pot size may expose seedlings to injuries as herbicides can move downward and come into contact with the root system. On the other hand, lower herbicide doses may be used in pots than in the field (Dixon and Clay 2004). Graminicides have proved to be safe enough, also in plastic greenhouse conditions, but dicots and occasionally occurring *Carex* spp. are difficult to control.

In future, one of the biggest challenges is to find a good control for *E. ciliatum*, which is well-adapted to container-based nurseries (Altland and Cramer 2006). In sandy soil conditions, metamitron has had poor impacts on *E. ciliatum*, but propyzamide has produced both pre- and post-emergence effect on *E. ciliatum* (Dixon and Clay 2004).

In the experiments presented here, relatively high concentrations were used to find out the tolerance of Norway spruce seedlings grown using pure peat as the substrate. Some negative effects, e.g. needle discoloration and stunted growth, were recoverable as shoot growth continued normally in the following spring. However, even slighter symptoms that remained, e.g. tip burning and dwarf needles, are clear defects, which will lead to rejection of these seedlings at the grading stage.

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# Effect of seedling size on their long-term survival in afforestation of former agricultural land

*Jyrki Hytönen*

Finnish Forest Research Institute, Kannus Research Unit, P.O. Box 44, FI-69101 Kannus, Finland.
jyrki.hytonen@metla.fi, tel. +358-102113405, fax +358-102113401

**Key words**
seedling size, survival, growth, afforestation

### Introduction
The ground vegetation on agricultural land completely differs from that on land that has been continuously forested. The development of ground vegetation on afforested former agricultural land is fast and vigorous, and many of the weeds growing on former fields are very aggressive in terms of their growth and reproductive vigour. Plants growing on former fields, especially grasses and herbs, retain their dominant role for a long time after afforestation. Following soil preparation, these former cultivated areas are first taken over by annual and biannual weeds emerging from the seed bank, but grass species take over after a couple of years. Weeds compete with tree seedlings for light, water, and nutrients, and they can also contribute to increased risk of attacks by pests and diseases (e.g. vole damage). Efficient vegetation control increases the probability of survival of tree seedlings, their growth, and reduces the risk of damage by various agents (e.g. Hytönen & Jylhä 2005, 2008).

Since the number of herbicides available and their use in forestry in Finland has been drastically reduced during the past decade, alternative methods are needed. Among these is the choice of soil preparation method and the size of seedlings used, as these can have an significant effect on the outcome of afforestation. The most important indicators of the outcome of afforestation are the survival and height growth of tree seedlings (Parviainen 1990). Many studies have demonstrated that bare-rooted seedlings survive and grow better than containerized seedlings (Hauberg 1971, Kinnunen 1989, Hytönen & Jylhä 2008), but in some cases containerized seedlings can have higher initial growth than bare-rooted seedlings (Nilsson & Örlander 1999). However, the outcome of afforestation may depend more on seedling size than on seedling type. The aim of this study was to investigate the effect of tree seedling size on seedling growth and survival in the afforestation former arable land over a period of 11 years.

### Material and methods
The afforestation of former agricultural land with Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.), silver birch (*Betula pendula* Roth), and downy birch (*Betula pubescens* Ehr.) was studied in sixteen field experiments established in different parts of Finland in 1990 and 1991. Bare-rooted 3- or 4-year-old Norway spruce and Scots pine seedlings and 1-year-old containerized birch seedlings were planted in these experiments. The experimental design was randomized blocks with two to five replications. With an eye to measuring the seedlings, the usual practice was to set up two 50 m$^2$ circular sub-sample plots in every sample plot. Altogether, 995 spruce seedling, 1174 pine seedlings, 1548 silver birch seedlings,
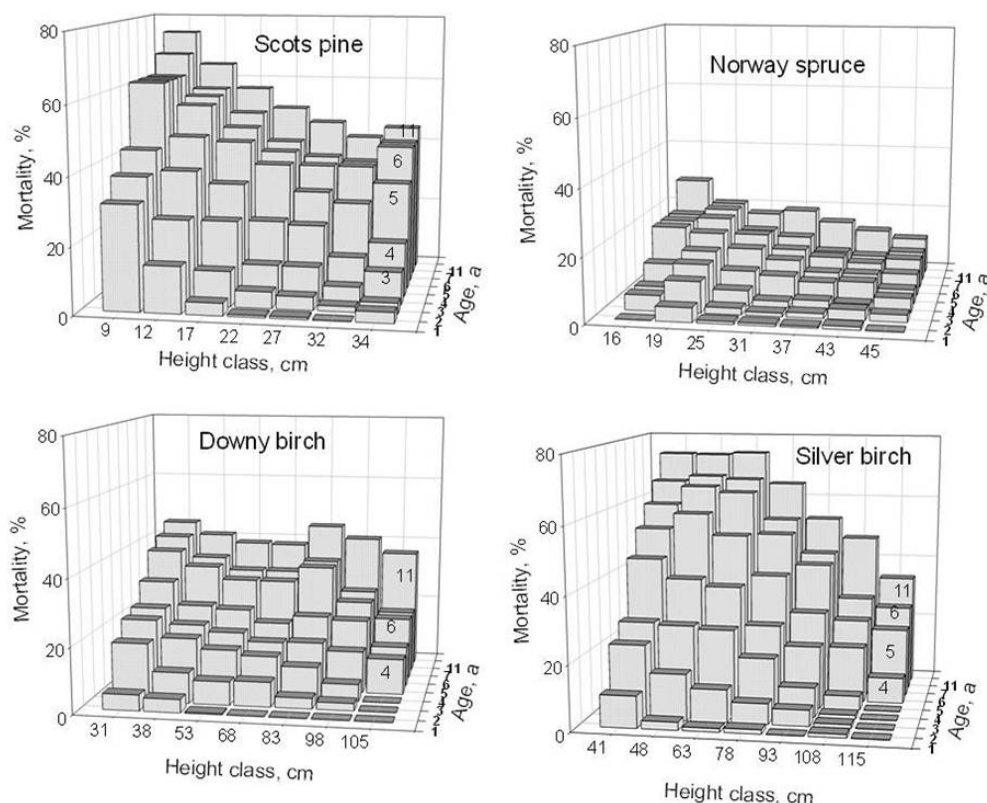
*Figure 1. The mortality of Scots pine, Norway spruce, downy birch and Silver birch seedlings in different height classes.*

and 1542 downy birch seedlings were measured for the first time in the autumn following planting. Their location in the sub-sample plots was mapped to enable the development of individual seedlings to be monitored. The same seedlings were measured annually for seven consecutive years. The final measurement round was completed at the end of the 11th growing season. The seedlings were divided into height classes based on their heights as measured in the first autumn after planting. Seedling height and mortality is reported in these initial height classes.

**Results and discussion**

The shorter the seedlings were in the first autumn following planting, the higher was their mortality during the following years (Fig. 1). Seedling mortality continued to grow over the entire study period. The mortality of Norway spruce seedlings was the lowest and that of Scots pine and silver birch seedligns the highest. The mortality of small Norway spruce, Scots pine, and silver birch seedlings was double than that of those in the uppermost height classes. In the case of downy birch, the effect of seedling height was also high during the first post-planting years, but it then declined at age 11 years.

Small seedlings had grown less than the larger seedlings (Fig. 2). For example, the Scots pine seedlings in the lowermost height class were 203 cm tall and those in the uppermost height class were 427 cm tall after 11 growing seasons.

Seedling production practices in forest tree nurseries have changed radically during the past few decades. In Finland, bare-rooted seedlings have been almost completely replaced by containerized stock, which is usually composed of smaller and younger seedlings. For example,
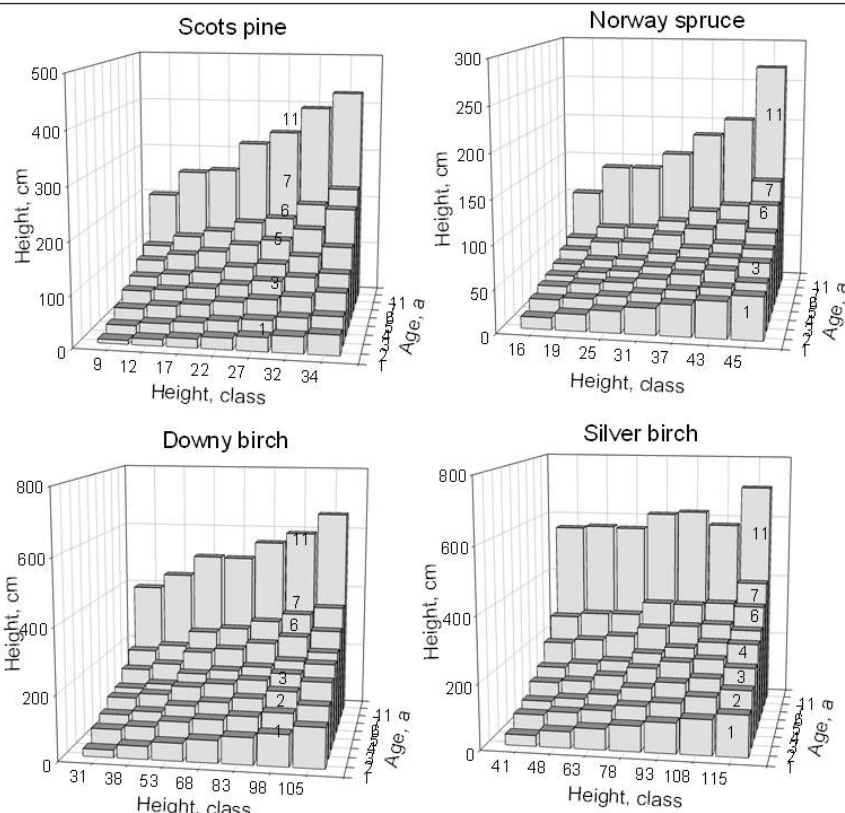
*Figure 2. The height growth of Scots pine, Norway spruce, downy birch, and Silver birch seedlings in different height classes*

in 1980, 66% of all Scots pine seedlings produced were bare-rooted, while by 2007 the production of bare-rooted seedlings had ceased (Peltola 2008). This study shows that seedlings size is a good and perhaps even a better indicator of afforestation success than seedling type. In some cases, the initial growth and survival of containerized Norway spruce seedlings can be higher than that of bare-rooted seedlings (Nilsson & Örlander 1995, Nilsson & Örlander 1999). The main reason for the success of taller seedlings is probably in that they are considered to be more competitive against ground vegetation than smaller seedlings (Jobidon et al. 2003). Even though the height of the seedlings in this study was not measured immediately after planting, but instead at the end of the first growing season, the study still reflects the effect of size of the planted seedlings. The need for effective vegetation control increases as seedling size decreases, because of the reduced competitiveness of small seedlings. The size of containers and even the age of containerized seedlings produced has also increased, and thus it is possible to choose seedling size and type according to site requirements.

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# Effects of competing vegetation and post-planting vegetation control on survival and growth of Scots pine, Norway spruce and Silver birch seedlings on former agricultural land

*Paula Jylhä* and *Jyrki Hytönen*

Finnish Forest Research Institute, Kannus Research Unit, P.O. Box 44, FI-69101 Kannus, Finland
paula.jylha@metla.fi

**Key words**

Vegetation control, herbicides, mulch, cover crop, vole damage, weed cover, Pinus sylvestris, Picea abies, Betula pendula

## Introduction

Former agricultural lands are challenging sites for afforestation. Due to agricultural history, the soils are more fertile than forest sites and they contain large banks of germinable seeds. The development of ground vegetation after soil preparation is fast, and competition from water, nutrients and light between tree seedlings and the weed species can be extremely severe. Consequently, weed control is one of the most important silvicultural measures to be carried out when establishing a plantation on an abandoned field. This paper is a review into the effects of competing vegetation and post-planting weed-control methods on survival and growth of Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L.) and silver birch (*Betula pendula* Roth) seedlings planted on former agricultural land. The complete results from the 11-year follow up have been reported in Hytönen & Jylhä (2005) and Jylhä & Hytönen (2006).

## Material and methods

The experiment was established as a randomized block design with tree replications on mineral soil in southern Finland in 1991 (Table 1). Due to complete soil preparation, the soil was free from vegetation when planting the seedlings. Soil active herbicides were applied soon after planting. Foliar active herbicides were sprayed when the weeds had sprouted up and were susceptible to these treatments. In addition to herbicides, mulching with 50 cm * 50

Table 1. Treatments applied in the weed control experiment. S = soil active, F = foliar active; Pi = Scots pine, Sp = Norway spruce, Bi = Silver birch.

| Treatment | Abbreviation for treatment | Brand name or species | Mode of action | Follow-up, years | |
|---|---|---|---|---|---|
| | | | | Pi, Sp | Bi |
| Control | CONT | | | 11 | 11 |
| Particle board mulch | MULCH | | | 11 | 11 |
| Cover crop | CLOV | *Trifolium repens* | | 11 | 11 |
| Terbuthylazine | TERB | Gardoprim | S (+ F) | 11 | 11 |
| Hexazinone | HEX | Velpar L | S + F | 6 | - |
| Chlorthiamid | CHLO | Prefix | S | - | 11 |
| Dichlobenil | DICH | Casoron G | S | - | 11 |
| Glyphosate | GLYP | Roundup | F | 11 | 6 |
| Terbuthylazine+glyphosate | TERB+GLYP | Folar 460 SC | S + F | 11 | - |
| Sethoxydim | SETH | Nabu | F | 6 | 6 |
| Pendimethalin | PEND | Stomp | S | 6 | 6 |

cm particle board and clover as a cover crop were tested. The cover percentage and species composition of competing vegetation was assessed on three post-planting growing seasons, and seedling size, vitality and causal agents of potential damage were recorded several times during the 11-year research period (see Hytönen & Jylhä 2005 and Jylhä & Hytönen 2006). Analysis of variance was used to test the statistical significance of the weed control treatments.

### Results and discussion

Most of the studied herbicides significantly retarded the increase in weed cover on the initially weedless plots from two to three years, and the cover crop promoted increase in cover percentage. Most soil active herbicides controlled ground vegetation more efficiently than the other treatments. Of the studied herbicides, only glyphosate is still on the market. In the experiment, the effect glyphosate treatment lasted 1 – 2 years.

The responses of the studied tree species to increasing competition from ground vegetation were found to differ. Birch seedlings appeared to benefit most of all from vegetation control in terms of height growth (Fig. 1). The mean height of birch and pine seedlings decreased linearly with increasing vegetation cover. Their mortality, however, started to increase markedly only when the vegetation cover had reached the level of 60 – 80%. Vegetation cover did not significantly affect spruce height growth and mortality. High vegetation coverage and small seedling size increased the risk of vole damage to the birch and pine seedlings.

The benefits of vegetation control at early stage were obvious throughout the follow-up period. After 11 years, the highest stand volume on the herbicide-treated birch plots was 3-fold as compared to the control plots (34.2 m³ha⁻¹ vs. 11.6 m³ha⁻¹) (Fig. 2). In the case of
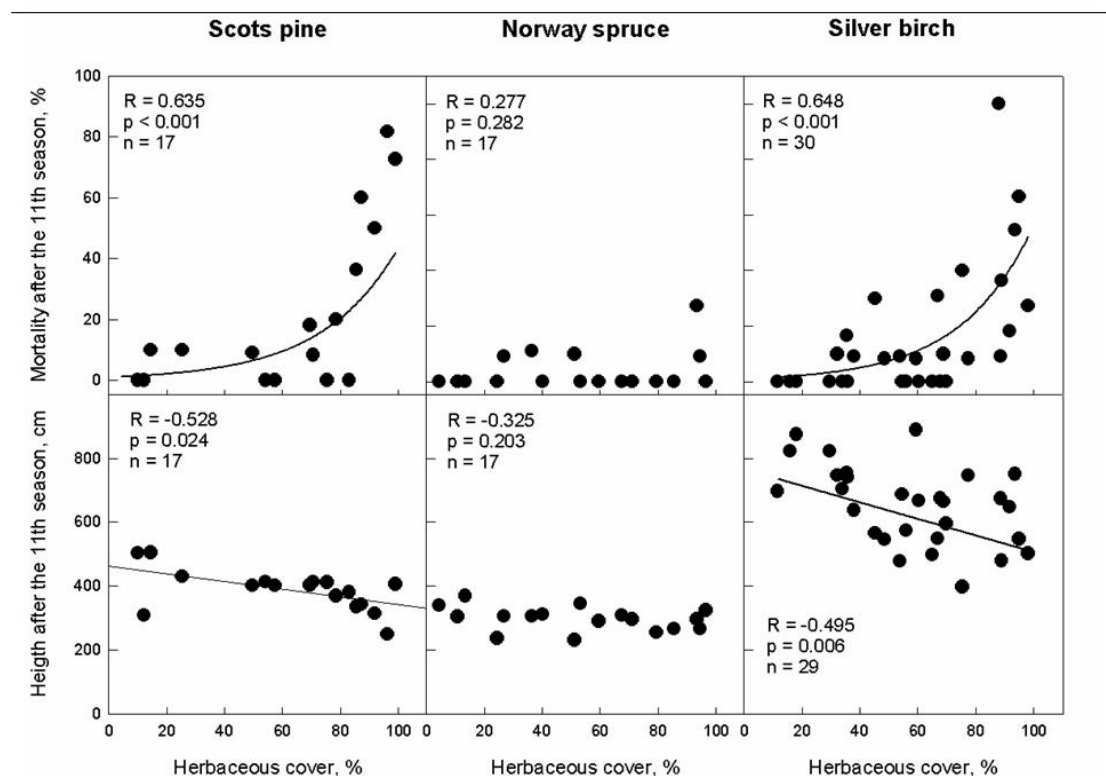


*Figure 1. Effect of mean vegetation cover percentage in the 1ˢᵗ, 2ⁿᵈ and 3ʳᵈ growing seasons on mortality and mean height of the seedlings 11 years after planting.*
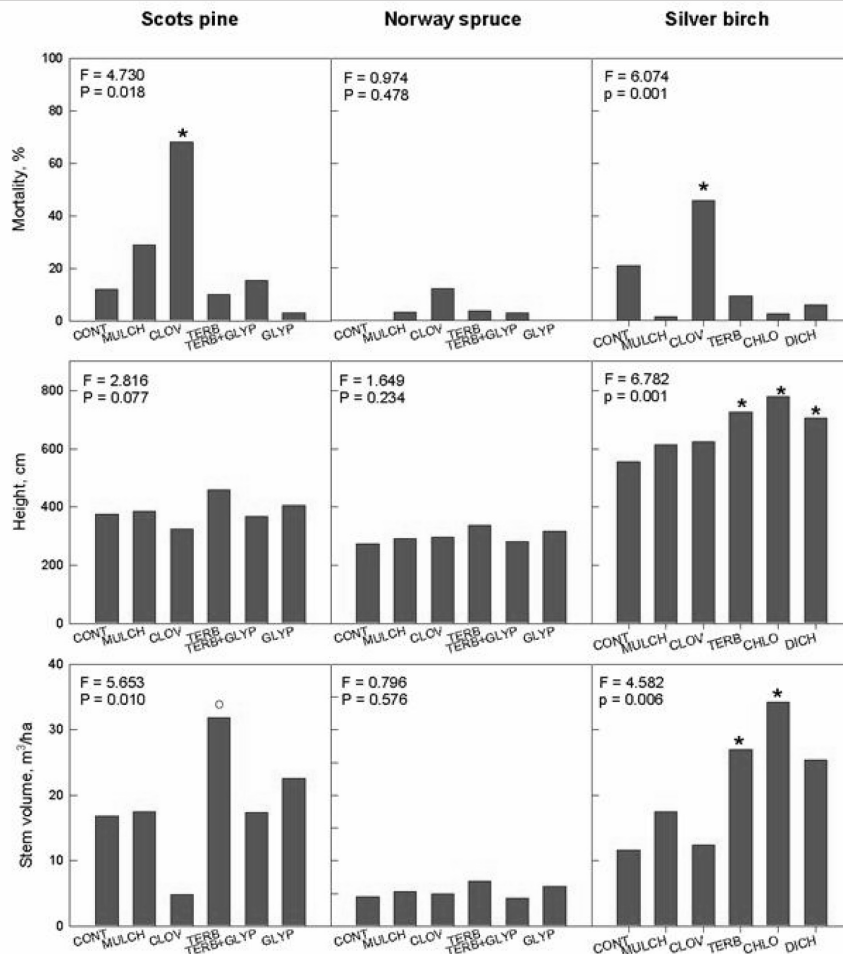
Figure 2. Effect of weed control on the mortality, seedlings' mean height and stand volume 11 years after treatments. The asterisks above the bars indicate the treatments significantly differing from the control treatment according to the Dunnet's test.

pine, a stand volume of almost 2-fold was recorded on the best herbicide-treated plots as compared to the untreated ones (31.8 m³ha⁻¹ vs. 16.8 m³ha⁻¹). Furthermore, seedling mortality on the birch control plots (21%) was almost 3.5-fold as compared to the mean seedling mortality on the herbicide-treated plots (6%). In the case of pine, the mortalities on the herbicide-treated plots did not significantly differ from the untreated plots. The growth and mortality of spruce was independent of treatment. Clover as a cover crop proved to be an ineffective weed control method both in terms of seedling growth and survival. The application of mulch decreased birch mortality, but it did not, however, affect the growth of any of the studied species. To be effective the mulches should probably have been larger in order to sufficiently reduce competition from nutrients and water.

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# Application of herbicides in poplar nurseries

*Verica Vasic[1], Branko Konstantinovic[2], Sasa Orlovic[1]*

[1] University of Novi Sad, Institute of Lowland Forestry and Environment, Antona Cehova 13 P.O. Box 117, 21000 Novi Sad, Serbia vericav@uns.ns.ac.yu
[2] University of Novi Sad, Faculty of Agriculture, Trg Dositeja Obradovica 8  P.O. Box 117, 21000 Novi Sad, Serbia

**Key words**
weeds, herbicides, poplar

## Introduction

Poplar nurseries are ideal place for development of rich floral and diverse weed vegetation due to wide between-row spacing, and open stand during early stages of development. Considering the care measures applied the weeds in forest nurseries are very similar to weed species found in field row crops (Konstantinović 1999). Control of weediness is very significant especially in nursery production of seedling stock, because the quality seedling stock is the basic prerequisite for successful establishment of poplar plantation and other forest species. Today, there are several means for weed control in nurseries, but there is also an increasing tendency to replace them by quicker and more efficient means of weed control. Investigation of the possibilities of applying herbicides in production of poplar nursery plants pointed out to many advantages of their application in relation to mechanical weed control. Usage of herbicides decreases the cost of soil cultivation and competition between weeds and nursery plants, and increases their quality and survival percentage. Several authors Anselmi (1984), Zekic (1984), Sixto et al. (2001) and some others pointed out to the economy of herbicide application in nurseries.

## Materials and methods

Testing of herbicides applied in poplar nursery plants production was done during 2002 - 2003. Field trials were set up in a rendomized block design with four replicates. Cuttings of three poplar clones Pannonia, B229 and Pe19/66 were used for experimental fields establishment. With the aim of more successful control of greater number of weed species the following combination of herbicides was applied: acetochlor + azafenidin, acetochlor + metribuzin and dimethenamid + linuron. The herbicides were applied after planting and before the growth of poplar cuttings and weeds. The herbicide efficiency was assessed at 15, 30 and 45 days after the treatment, and at the same time the estimation of herbicide phytotoxicity was done. When choosing herbicides, besides weed composition, spectrum of herbicide activity, selectivity, time and method of application the soil properties must also be taken into consideration. Trials were set up in two localities differing in physicochemical soil properties (clay form of fluvisol and sandy form of fluvisol).

## Results and discussion

On the basis of a two-year investigation period of herbicide efficacy in weed control regarding production of poplar nursary plants, some differences in weed flora composition among tested localities were observed. **Different composition** of the **weed flora in trial areas was af-**
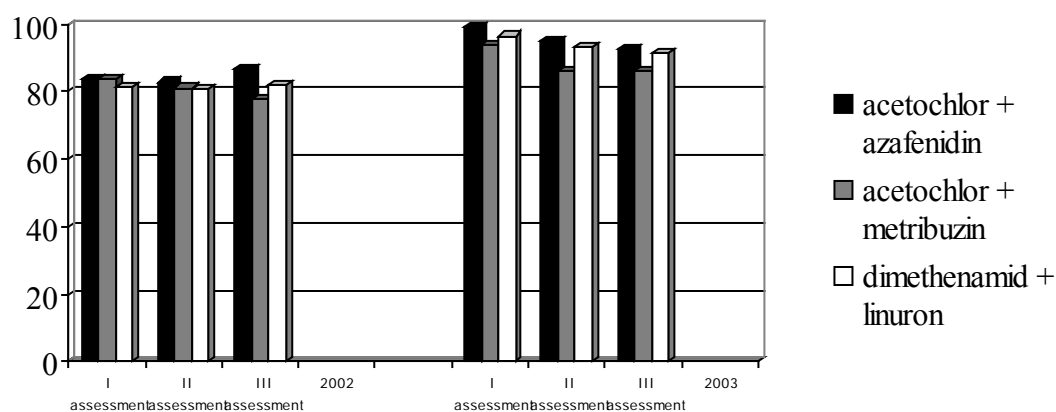
*Graph. 1 - Herbicide efficacy tested on the clay form of fluvisol*

**fected by differences in** chemical and physical soil properties during investigation period. Tested herbicides, i.e. combination of herbicides exerted high efficacy in controlling weed flora in studied localities. The effects that combination of herbicides acetochlor + azafenidin exerted during two-year investigation period in both localities were the greatest. Differences in physicochemical soil composition also influenced the behavior and herbicide action in such a way that metribuzin applied on soils of lighter mechanical composition (sandy form of fluvisol) in combination with acetochlor exerted phytotoxic effect on poplar nursery plants. Herbicide metribuzin which is very soluble and motile in sandy soils (Ahrens 1994) penetrated the deeper layers of soil within the zone of root system, and caused damages manifested in the form of leaf necrosis, and even leaf yellowing, and deterioration of some rooted cuttings. Due to phytotoxic effect of metribuzin significantly lower percentage of rooted cuttings survival was observed on the plots treated with this herbicide. Gojkovic (1995) also mentioned that care should be taken when using herbicides in regard to mechanical soil composition, because if herbicides were applied on soil of lighter mechanical composition they could easily penetrate the zone of the root system and cause damages to planting material.
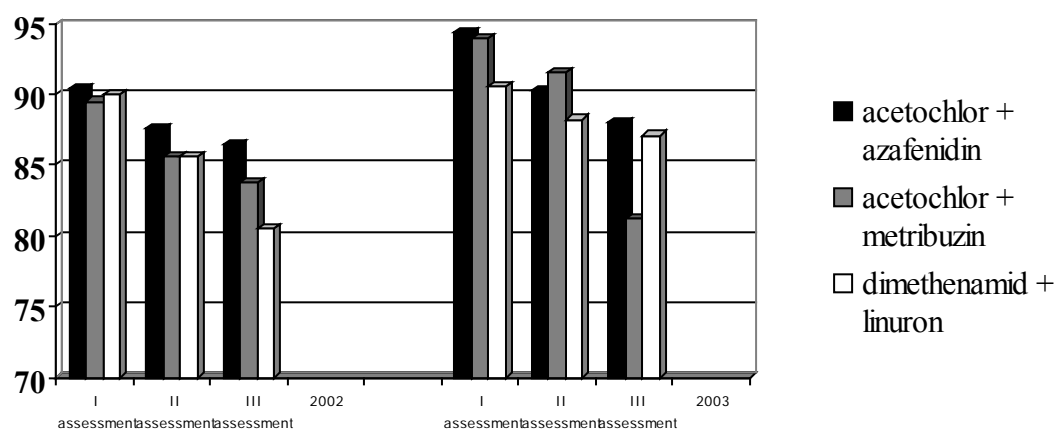
*Graph. 2 - Herbicide efficacy tested on the sandy form of fluvisol*

## Conclusions

Obtained results revealed that tested herbicide and their combinations exerted very good efficacy in regard to weed control in the studied localities, which enabled undisturbed development of poplar nursery trees. The best efficacy during investigation period was found for acetochlor + azafenidin combination in both localities. Tested herbicides had no phytotoxic effect on poplar nursery trees except for metribuzin, which applied in combination with acetochlor on soil of lighter mechanical composition had phytotoxic effect. Application of metrubizin on soils of lighter mechanical composition in poplar nursary plants production is not recommended due to above mentioned reason.

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# The Influence of Soil Preparation on Ground Vegetation and Subshrubs

*Antanas Malinauskas, Vytautas Suchockas*

Lithuanian Forest Research Institute, Girionys, Kaunas district, Lithuania

## Introduction

The success of forest regeneration and plantation establishment is considerably influenced by the competing vegetation. The effects of vegetation on tree seedlings survival, growth and development depends upon the characteristics of the planting area (Pavers, Reynolds 1999), species composition of the competing vegetation (Miller et al. 2003) and silvicultural treatments (Gemmel et al. 1996).

The aim of this work was to ascertain the influence of different soil preparation methods on the distribution of the competing vegetation in the clear-cuts, as well as on former farm-lands of different fertility and humidity.

## Materials and methods

Studies on the influence of different soil preparation methods on the distribution of competing vegetation were conducted in the clear-cuts of *hepatico-oxalidosum*, o*xalido-nemorosum* and a*egopodiosum* forest sites types and in stands of the same site types, i.e. deciduous with Norway spruce and broadleaved species, as well as on former farmlands of poor and fertile soils. The soil was prepared in August – September 2003-2005 years with 3-7 replications, the plantation was established in the spring of the following year. The biomass of weed vegetation was ascertained in the second half of August – the first half of September, severing it at the ground level in 40x50 cm sized sampling plots (10 sampling plots for each replication). Shading class of the ground vegetation on each seedling was assessed as follows: 0 - no shading, 1 - one quarter, 2 - half, 3 - three quarters of the seedling in shade and 4 - fully shaded (Hytönen, Jylhä, 2005).

## Results and discussion

In clear-cuts every mechanical soil preparation method reduced the biomass of ground vegetation (fig. 1).

With increasing soil preparation depth (to 40 cm) and the width of prepared strip (up to 100 cm), the mass of weeds decreased. The mass of weed vegetation depends also on soil preparation methods: furrow, elevated berm, inverted humus mound or disked trench stripe.
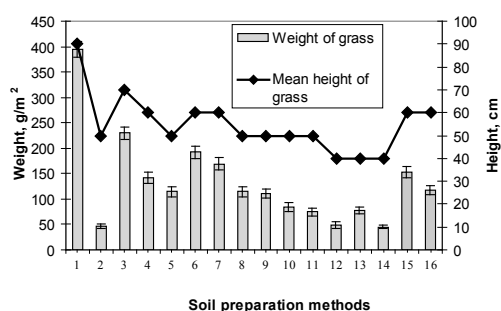


*Fig. 1 Owen-dry biomass and mean height of herbaceous and woody plants in fresh clear-cut areas depending upon soil preparation methods. 1-no site preparation, 2- furrow depth 10 cm, with 70 cm; Elevated berm: 3- height10 cm, 4- height 20 cm, 5-height 30 cm 6- width 40 cm, 7-widht 60 cm, 8-widht 80 cm, 9-widht 100 cm. Complete strips ploughing: 10-depth 10 cm, 11- depth 20 cm, 12-depth 30 cm, 13- width 60 cm, 14- width 100 cm. 15- disked trench stripe (height 20 cm, width 50 cm), 16- disked trench stripe (height 20.cm, width 100 cm)*

Soil preparation on former farmland have a distinct, but most often a significantly less influence than on forest soils. In the first year of plantations, the least biomass of weeds was found on furrows. Complete ploughing to the depth of 22-27 cm, preparation in mounds of inverted humus or weed-killing with Roundup reduced the biomass of weeds by up to 2 times (fig. 2). Soil preparation in ploughed tilts or inverted humus mounds reduced the biomass of weeds. In the second year, the differences in the mass of weeds among different soil preparation methods decreased.
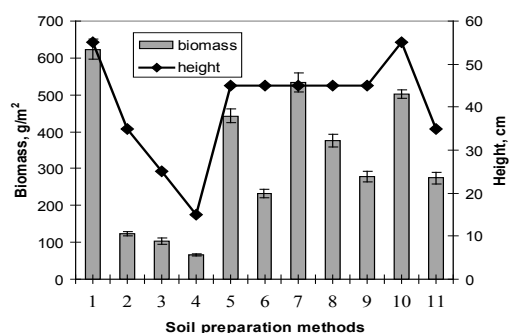


*Fig. 2. Dependance of oven-dry biomass and mean height of weeds upon fertile soil preparation methods on former agricultural lands*

*1-no site preparation, 2-furrow (depth 8-10 cm), 3-furrow (depth 15 cm), 4-Roundup (4 l ha⁻¹) + furrow (depth 15 cm), 5-complete site plowing (depth 22-27 cm), 6-Roundup (4 l ha⁻¹) + complete site plowing (depth, 22-27 cm), 7-tilt plowing (height 25 cm, width 75 cm, 8- disked trench stripe (height 20 cm, width 50 cm), 9-Roundup (4 l ha⁻¹) + disked trench stripe (height 20 cm, width 50 cm), 10-Roundup (4 l ha⁻¹), 11-inverted humus mounds (60 x 80 x 30 cm).*

Soil preparation have influence on the height of weeds. The height of ground vegetation depended upon soil preparation method, soil fertility and humidity, the species of grasses or herbs, as well as spring and summer weather conditions. The shading of seedlings reduced significantly their diameter growth ($Zd$), but had less influence on height increment ($Zh$), therefore the ratio $Zh/Zd$ of the trees have increased (Fig. 3).
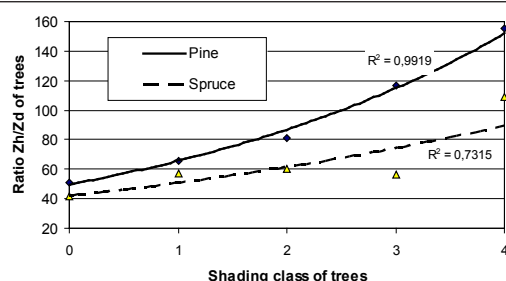


*Fig. 3. Influence of seedlings shading class on the ratio Zh/Zd of trees in 2 years forest plantation of Scots pine and Norway spruce.*

The seedlings become unstable for the mechanical impact of environment, they are bended under the weeds, snow and ice cover, and finally died. In the second year and later, in the spruce and other shading tolerated tree species plantations the weeds control is necessary if the seedlings are fully shaded, and for the heliophilous tree species (pine, birch) – if they are fully shaded or three quarters of the tree are in shade, especially if the shading was caused not by *Graminae* weeds.
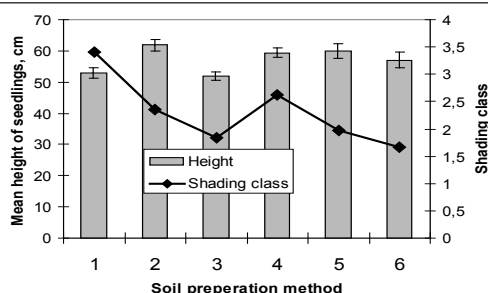


*Fig. 4. Shading class and seedlings height in 2 years Norway spruce plantation according to the soil preparation methods.*

*1-no site preparation, 2-complete site plowing, depth 25-27cm, 3-furrow depth 15 cm, with 100 cm, 4- disked trench stripe, height 20 cm, width 50 cm, 5-tilt plowing, height 30 cm, width 75 cm, 6- inverted humus mound (60 x 80 x 30 cm).*
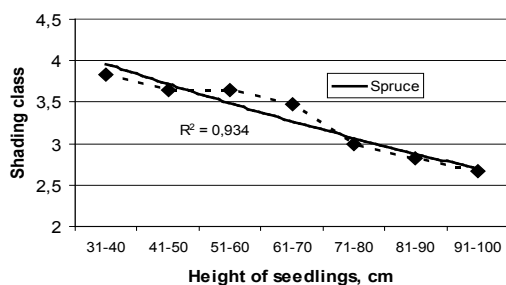
Fig. 5. Shading class of Norway spruce depending upon seedlings height

Shading class of seedlings, and related to it the extent of weeds control depended upon soil preparation method (Fig. 4) and initial height of seedlings (Fig. 5).

Having prepared soil in advance, weed control of the plantation in the first year is unnecessary (Vyachkilev et al. 1980). Having prepared the soil in relatively thin tilts (15-25 cm thickness), weeds fully recover already in the second year, while having prepared in relatively thick tilts (20-50 cm), maintenance of the plantation is necessary only in the third year (Maslakov et al.1978). In the second and the third year, weeds on ploughed tilts develop 2-4 times slower than on unprepared soil (Kovalyov 1986). Following soil preparation on former farmland, ground vegetation spreads already in the first year (Törmälä, 1982; Jukola, Sulonen, 1983). Even complete soil ploughing (tillage and harrowing before planting), leaving the soil weed-free, fails to ensure good development of seedlings. The seeds of annual plants sprout and quickly occupy the whole area (Ferm et al., 1994).

Direct preparation of the soil before establishing a plantation has a positive effect on the growth of tree-plants, but this effect is of short duration due to the fast spreading of weeds (Vares et al., 2001).

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# Tree seedlings growth in response to Himalayan balsam (*Impatiens glandulifera*) at two forest stands in Bavaria, Germany

*René Degenhardt[1], Martin Bachmann[2], Christian Ammer[1]*

1) Georg-August University Göttingen, Department of Silviculture and Forest Ecology of the Temperate Zones, Büsgenweg 1, 37077 Göttingen, Germany, rdegenh@gwdg.de, Christian.ammer@forst.uni-goettingen.de
2) Bavarian Forest Institute (LWF), Am Hochanger 11, 85354 Freising, Germany, martin.bachmann@lwf.bayern.de

## Introduction

Himalayan balsam (*Impatiens glandulifera*) is the tallest annual plant in Europe. It prefers humid to wet, nutrient rich, acidic to alkaline soils with high ground water levels or sites with high air humidity (Ludwig *et al.*, 2000). In the first half of the 19th century the species was introduced from the Himalaya as a garden ornamental and nectar producing plant. Since then it has invaded nearly all European countries and several states of the United States (Grime *et al.*, 1988; Toney *et al.*, 1998). As it can reach 2 meters height and produces up to 1600-4300 seeds per plant, it is supposed to be a strong competitor to other species (Beerling and Perrins, 1993; Pyšek and Prach, 1995; Kowarik, 2003). In fact there are two major concerns about the invasion of Himalayan balsam: first, the bastardisation of flora, which might be a problem in terms of nature conservation, and second, its potential detrimental effects on tree seedlings establishment and growth. In this study we focused on the second concern. Based on an experiment at two sites we tested the following research questions: (i) does Himalayan balsam restrict tree seedling growth and (ii) does mechanical weed control result in higher survival and growth of tree seedlings.

## Material and methods

In fall 2005 two experimental sites were established in Southern Bavaria. One site is located close to Irschenberg (47.848417 N, 11.906547 E), the other one close to Wasserburg (48.041564 N, 12.144822 E). The mean annual temperature in Irschenberg is 7.4 °C and the total annual precipitation is 1289 mm/a. The values for Wasserburg are 8.4 °C and 986 mm/a, respectively. The soils at Irschenberg are characterized by moderate fresh to fresh silt and at Wasserburg by moderate fresh to fresh, rocky, sandy silt. At both sites Himalayan balsam was already established at the start of the experiment. The study was carried out using a block design. We established three blocks at Irschenberg and two blocks at Wasserburg. Each block contained 12 plots and three treatments (i.e. 4 plots per treatment and block). The treatments were: (i) control (without any measures), (ii) mowing in July before Himalayan balsam releases its seeds, (iii) pulling out the entire plant. Survival and growth of natural regeneration, that was already present at the start of the experiment, was recorded at Irschenberg from 2005 to 2007. Survival and growth of planted Norway spruce (*Picea abies* (L.) Karst.) and Silver fir (*Abies alba* (Mill.)) was recorded at Wasserburg from 2005 to 2008. At both sites, tree seedlings survival and growth was recorded (on each plot) within circular sample units of two meters diameter in size. Each seedling in these sample units was marked. In October 2006 and 2007 seedling height and seedling diameter at three centimeters above ground were measured. Additionally,

only at Wasserburg, competition by bramble (*Rubus fruticosus*) was assessed by estimating the coverage of bramble within a circle of 30 cm around each seedling. At the Irschenberg site only the data of birch (Betula spec.) were evaluated.

A statistical analysis was done using ANOVA. Where the data were not normally distributed, the Kruskal-Wallis Test was used (Sachs and Hedderich, 2006). At the Wasserburg site multiple regression analysis was carried out additionally on a single tree basis. The dependent variables were seedling height growth and diameter growth, the independent variables were treatment (coded as dummy variables), tree species (coded by another dummy variable), initial seedling height, diameter, and coverage by bramble. The calculations were done using R 2.8.1 and SAS 9.2.

### Results and Discussion

At Irschenberg height growth of birch in years 2006 and 2007 did not differ among the treatments. However, there was no correlation between the coverage by *Rubus fruticosus* and birch seedlings height growth.

*Table 1: Descriptive statistics of the height growth data of birch at Irschenberg in 2006 and 2007.*

| Treatment | Mean [mm] | SD [mm] | Variance | Number of plants | Year |
|---|---|---|---|---|---|
| control | 159.18 | 48.27 | 2330.15 | 44 | 2006 |
| cut with a sickle | 148.34 | 64.59 | 4171.90 | 50 | 2006 |
| eradicate | 136.83 | 70.75 | 5005.02 | 42 | 2006 |
| control | 156.17 | 59.02 | 3483.00 | 41 | 2007 |
| cut with a sickle | 160.00 | 48.89 | 2390.55 | 45 | 2007 |
| eradicate | 126.42 | 73.02 | 5331.38 | 24 | 2007 |

*Table 2: Descriptive statistics of the height growth data of Norway spruce at Wasserburg in 2006, 2007 and 2008.*

| Treatment | Mean [mm] | SD [mm] | Variance | Number of plants | Year |
|---|---|---|---|---|---|
| control | 122.50 | 46.76 | 2186.94 | 10 | 2006 |
| cut with a sickle | 105.29 | 28.34 | 803.30 | 14 | 2006 |
| eradicate | 101.87 | 41.50 | 1722.41 | 15 | 2006 |
| control | 143.86 | 113.45 | 12870.14 | 7 | 2007 |
| cut with a sickle | 92.08 | 49.30 | 2430.81 | 12 | 2007 |
| eradicate | 86.80 | 61.00 | 3721.29 | 10 | 2007 |
| control | 172.83 | 107.05 | 11459.77 | 6 | 2008 |
| cut with a sickle | 235.83 | 146.47 | 21453.61 | 12 | 2008 |
| eradicate | 252.00 | 161.77 | 26170.29 | 8 | 2008 |

*Table 3: Descriptive statistics of the height growth data of Silver fir at Wasserburg 2006, 2007 and 2008.*

| Treatment | Mean [mm] | SD [mm] | Variance | Number of plants | Year |
|---|---|---|---|---|---|
| control | 50.78 | 29.24 | 854.69 | 9 | 2006 |
| cut with a sickle | 100.00 | 53.87 | 2902.00 | 11 | 2006 |
| eradicate | 78.92 | 41.53 | 1724.99 | 12 | 2006 |
| control | 194.71 | 96.96 | 9401.57 | 7 | 2007 |
| cut with a sickle | 281.64 | 104.93 | 11010.25 | 11 | 2007 |
| eradicate | 194.36 | 75.19 | 5654.25 | 11 | 2007 |
| control | 331.17 | 106.98 | 11443.77 | 6 | 2008 |
| cut with a sickle | 407.09 | 100.45 | 10089.29 | 11 | 2008 |
| eradicate | 332.00 | 171.87 | 29540.00 | 11 | 2008 |

At the Wasserburg site there were no significant differences for Norway spruce among the three treatments in any year. Only in 2006 for silver fir, differences between the treatments "control" and "cut with a sickle" could be revealed. However, these differences could not be found in the following years. Alike, we did not find a correlation between the coverage by *Rubus fruticosus* and seedlings height growth of both tree species at Irschenberg.

In summary, our results indicate that Himalayan balsam has no impact on tree seedlings height growth. Obviously, it does not affect resource availability to a level where seedlings growth is hampered. However, it might have some effects on tree recruitment, but not for the development of already established seedlings. According to Kowarik (2003) Himalayan balsam may fill a so far unused ecological niche. In the riparian forest of Hördt/Rhineland-Palatinate Vor and Schmidt (2008) have shown that some invasive plants have been able to establish successfully because they are able to use free resources. This does, however, not necessarily mean that there is a detrimental effect on the seedlings.

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# Programme

## Plenary sessions

| Time | Presenter | Affiliation | Title |
|---|---|---|---|
| center | **Tuesday 5 May** | | |
| 08:30 | Niels Elers Koch | Domain Committee member of FPS | Opening address |
| | Nick McCarthy | Chairman of COST E47 | Welcome |
| | Marion Karmann | Forest Stewardship Council FSC International Germany | Certification and forest vegetation management |
| | Nick McCarthy | Waterford Institute of Technology Chemical and Life Sciences Ireland | Trends in Forest vegetation management in Europe in the 21st century |
| 10:00 | **Break** | | |
| 10:30 | Jyrki Hytönen | Finnish Forest Research Institute Finland | Long-term response of weed control intensity on Scots pine and Norway spruce survival and growth on arable land |
| | Verica Vasic | University of Novi Sad Institute of Lowland Forestry and Environment Serbia | Herbicide weed control in pedunculate oak (Quercus robur) forest regeneration |
| | A Fini | University of Florence Department of Horticulture Italy | Experience on mulching shade tree species in Italy |
| | Thomas G. Papachristou | Forest Research Institute National Agricultural Research Foundation Greece | Grazing of livestock to perform herbaceous vegetation control in coppice oak forests in Greece: trade-offs between herbs and oak sprouts in foraging decisions |
| 12:00 | **Lunch** | | |
| 13:00 | Nelson Thiffault | Direction de la recherche forestière Ministère des Ressources naturelles et de la Faune du Québec Canada | Development of non-chemical forest vegetation management in Quebec, Canada |
| | L Hamberg, | Finnish Forest Research Institute Finland | Effects of different management methods on Sorbus aucuparia and Populus tremula sprouting in mesic forests in finland |
| | Niclas Scott Bentsen | University of Copenhagen Centre for Forest, Landscape and Planning Denmark | Afforestation with beach and oak on heavy soils – mortality and growth as affected by vegetation management strategies |
| | Phillip E. Reynolds | Canadian Forest Service Great Lakes Forestry Centre Canada | Vegetation Management to Optimize Carbon Assimilation and Ameliorate Climate Change – Canada's Long-term Soil Productivity (LTSP) Project |
| | Simon Bilodeau-Gauthier | University of Quebec in Montreal Centre for Forest Research Canada | How best should we manage hybrid poplar plantations? Interactions of site preparation, vegetation control and fertilization |
| | Petr Zahradnik | Forestry and Game Management Research Institute Czech Republic | Vegetation management in the Czech Republic |
| 15:10 | **Break** | | |
| 15:40 | Michael Stoltze | | FVM from the view of an NGO |
| | Marion K. Seier | CABI Europe-UK UK | Biological Control of Invasive Weeds - A Tool for Integrated Vegetation Management |
| | Hans Peter Ravn | University of Copenhagen Centre for Forest, Landscape and Planning Denmark | Effects of different weed control methods on flora and fauna |
| 17:30 | Poster presentations | | |
| 18:20 | End of poster presentations | | |
| 19:00 | **Dinner** | | |

### Wednesday 6 May

| Time | Presenter | Affiliation | Title |
|------|-----------|-------------|-------|
| 07:00 | **Breakfast** | | |
| 08:00 | **Departure for field trip** | | |
| | Klaus Enevoldsen Lars Rasmussen | Municipality of Vejle | Forestry in Denmark, why and how |
| | | | Forest Vegetation Management from the view of a public forest owner |
| | Palle Madsen | University of Copenhagen | Field experiment: Direct seeding under nurse crops |
| | Frans Theilby Niclas S Bentsen | University of Copenhagen | Field experiment: Afforestation on heavy soils |
| 18:00 | **Return from field trip** | | |
| 19:00 | Dinner | | |

### Thursday 7 May

| Time | Presenter | Affiliation | Title |
|------|-----------|-------------|-------|
| 07:00 | **Breakfast** | | |
| 08:00 | *Marie-Charlotte Nilsson* | Agricultural University of Sweden Sweden | Plant-plant interactions |
| | *Agnes Sourisseau* | Independent Landscaper, France | Direct seeding of forest tree species: Potentials, constraints and reality |
| | *Magnus Löf* | Agricultural University of Sweden | |
| | *Palle Madsen* | University of Copenhagen, Denmark | |
| | *Sven Wagner* | Dresden University of Technology Institute of Silviculture and Forest Protection Germany | Canopy effects on vegetation |
| 10:10 | **Break** | | |
| 10:40 | *Kjersti Holt Hanssen* | Norwegian Forest and Landscape Institute Norway | Competition for both light and below-ground resources determines the growth of seedlings and weeds in forest gaps |
| | *Bernard Prévosto* | Cemagref UR Ecosystèmes méditerranéens et risques France | Regeneration and diversification of Pinus halepensis stands in southern France: impacts of different vegetation and soil treatments |
| | *Philippe Balandier* | Cemagref Research Unit on Forest Ecosystems France | Foundations of the cover crop technique and potential use in afforestation |
| | *Axel Granhus* | Norwegian Forest and Landscape Institute Norway | Natural regeneration of Norway spruce on scarified clear-cuts in southeast Norway. |
| 12:00 | **Lunch** | | |
| 13:00 | *Marine Dodet,* | MGVF, Laboratoire d'Etude des Ressources Forêt-Bois France | Natural regeneration after storm: positive and negative effects of vegetation on forest regeneration |
| | *Boutheina Adili* | Faculty of Sciences of Bizerte Tunisie | Natural regeneration of Pinus pinea in Tunisia as influenced by light, litter biomass and understorey vegetation |
| | *Fernando Valladares* | Instituto de Recursos Naturales CCMA, CSIC Spain | The role of understorey in Mediterranean forestry in the view of climate change |
| | *Noemie Gaudio* | Cemagref Research Unit on Forest Ecosystems France | Influence of three understorey species (Calluna vulgaris, Pteridium aquilinum, Molinia caerulea) on survival and growth of Pinus sylvestris seedlings. |
| 14:30 | **Break** | | |
| 15:00 | *Philippe Balandier* | Cemagref Research Unit on Forest Ecosystems France | Methods for describing light capture by understorey weeds in temperate forests: consequences for tree regeneration |
| | *Christian Messier* | Université du Québec à Montréal Centre d'Étude de la Forêt (CEF), Dép. Sci. Biol. Canada | Can plantations develop understory biological and physical attributes of naturally regenerated forests? |
| | *Philip G. Comeau* | University of Alberta Dept. of Renewable Resources Canada | Vegetation management and sustainable management of mixedwood stands in western Canada's boreal forest |
| | *Lluís Coll* | Centre Tecnologic Forestal de Catalunya Spain | Analyzing shrub control patterns in Mediterranean forest by basic site and stand structural patterns |
| 19:00 | **Dinner** | | |

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# Poster presentations

| Presenter | Affiliation | Title |
| --- | --- | --- |
| Henna Vartiamäki | Finnish Forest Research Institute<br>Vantaa Research Unit<br>Finland | Biological sprout control with *Chondrostereum purpureum* in Finland |
| Marja Poteri | Finnish Forest Research Institute<br>Suonenjoki Unit<br>Finland | Constraints in vegetation management in container forest tree seedling production |
| Jyrki Hytönen | Finnish Forest Research Institute<br><br>Finland | Effect of seedling size on their long-term survival in afforestation of arable land |
| Paula Jylhä | Finnish Forest Research Institute<br><br>Finland | Effects of competing vegetation and vegetation control on survival and growth of Scots pine, Norway spruce and Silver birch planted on former agricultural land |
| Philip G Comeau | University of Alberta<br>Dept. of Renewable Resources<br>Canada | Effects of spot brushing to enhance spruce growth in regenerating boreal mixed-wood stands |
| Philip G Comeau | University of Alberta<br>Dept. of Renewable Resources<br>Canada | Effects of Vegetation Control Treatments for Release of Engelmann Spruce from a Mixed-Shrub Community in Southern British Columbia – Year 15 results. |
| F Tavankar | Islamic Azad University of Khalkhal branch<br>Faculty of Natural Resources<br>Iran | Logging Damages on Forest Regeneration and Soil |
| Verica Vasic | University of Novi Sad<br>Institute of Lowland Forestry and Environment<br>Serbia | Application of herbicides in poplar nurseries |
| Vytautas Suchockas | Lithuanian Forest Research Institute<br>Department of Silviculture<br>Lithuania | The Influence of Soil Preparation on Ground Vegetation and Subshrubs |
| Bernard Prévosto | Cemagref<br>UR Ecosystèmes méditerranéens et risques<br>France | Planting of Mediterranean oaks in open-field conditions using *Pinus halepensis* and *Coronilla valentina* as nurse plants: results of an experimental plantation after one year. |
| Yancho Naidenov | Forest Protection Station<br>Bulgaria | The biocontrol as element of the forest management in Bulgaria |
| Edward Daly | Waterford Institute of Technology<br>Ireland | Achieving effective control of *Rhododendron ponticum* L. |
| Seamus Forde | Waterford Institute of Technology<br>Ireland | The development of an Invasive Species Hazard Classification System for Irish Forests |
| Christian Ammer | Georg-August University Göttingen<br>Department of Silviculture and Forest Ecology of the Temperate Zones<br>Germany | Does invasive Himalayan balsam (*Impatiens glandulifera*) affect the growth of tree seedlings |