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Quality management of forest regeneration activities

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Academic dissertation

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ABSTRACT

The purpose of this thesis was to find out what are the main factors that have to be taken into account in planning, controlling and improving the quality of forest regeneration activities. The forest regeneration services provided for the non-industrial privately-owned forests in Southern Finland by the local Forest Owners' Associations (FOAs) were used as an example. Since the original assumptions of quality management were not completely valid in this context, Lillrank's classification of production processes was used. The classification fit well for this field of services, and a tentative framework for modelling and standardisation of forest regeneration service processes was proposed for further testing. The results of regeneration and costs varied considerably between the service providers at different levels. The jointly analysed inventory results and feedback provided a sound starting point for tackling the main causes of the statistical variation observed. The inventory results indicated that the selection of proper methods of regeneration and the way they were executed were the most common factors influencing the quality of service outcomes. The cost–quality analysis of the two most common chains of regeneration revealed an improvement potential for the cost-efficiency of these services. In the case of Norway spruce (*Picea abies* (L.) Karst.) planting the regeneration costs were only weakly related to quality. As for direct seeding of Scots pine (*Pinus sylvestris* L.) direct seeding, a significant positive correlation was found. However, the selection of this chain of regeneration for the MT (*Myrtillus* type) and more fertile site types produced poor regeneration results. In the case of Norway spruce planting, the most important factor explaining the outcomes was soil preparation. Selection of mounding produced better results than patching and disc trenching. In the FOAs, the effect of quality management interventions was observable especially regarding the improvement of resource allocation and practices related to soil preparation.

Keywords: Silvicultural services, Quality control, Cost–quality relationship, *Picea abies*, *Pinus sylvestris*

Kankaanhuhta, V. 2014. Metsänuudistamisen laatutyön perusperiaatteet. Dissertationes Forestales 174. 93 s. Saatavissa:
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TIIVISTELMÄ

Tutkimuksen päämääränä oli selvittää korkealaatuiseen metsänuudistamistulokseen tähtäävän uudistamistoiminnan suunnittelussa, hallinnassa ja kehittämisessä vaadittavat tekijät. Esimerkkinä toimivat Etelä-Suomen yksityismetsiin metsänuudistamispalveluja tuottavat metsänhoitoyhdistykset. Koska laatujohtamisen perusoletukset eivät olleet kaikilta osin päteviä yksityismetsien uudistamistoiminnassa, käytettiin apuna Lillrankin kehittämää tuotantoprosessien luokittelua. Tämä luokitus soveltui hyvin tutkittavien palvelujen kehittämiseen, ja sen pohjalta luotiin alustava kehittämismalli metsänuudistamisen palveluprosessien mallinnukseen ja vakiointiin. Tutkimustulokset paljastivat merkittävää vaihtelua sekä uudistamistuloksissa että palvelujen kustannuksissa eri toimijoiden välillä. Yhdessä analysoitu palaute laatuinventoinneista mahdollisti kehittämistyön, jossa keskityttiin merkittävimpien tilastollista vaihtelua aiheuttavien tekijöiden hallintaan. Merkittävimmät uudistamisen laatuun vaikuttavat tekijät olivat sopivimpien uudistamismenetelmien valinta sekä niiden asianmukainen toteutus. Kahden yleisimmän uudistamisketjumme, kuusen istutuksen ja männyn kylvön, kustannus-laatu analyysi paljasti metsänuudistamispalvelujemme kustannustehokkuuden kehittämispotentiaalin. Kuusen istutuksen osalta uudistamiskustannukset korreloivat laadun kanssa vain heikosti. Männyn kylvössä uudistamiskustannusten ja tulosten välillä oli positiivinen korrelaatio. Uudistamistulokset olivat kuitenkin heikkoja tuoreilla kankailla ja niitä viljavammilla kasvupaikoilla. Kuusen istutuksessa merkittävin uudistamistulokseen vaikuttava tekijä oli sopivimman muokkausmenetelmän valinta: mätästys tuotti paremman lopputuloksen verrattuna laikutukseen tai äestykseen. Laatutyön vaikutus näkyi metsänhoitoyhdistyksissä selvimmin maanmuokkaustoiminnan resursoinnissa ja menetelmien muutoksena kohti parhaita käytäntöjä.

Avainsanat: metsänhoitopalvelut, laatujohtaminen, kustannus-laatu suhde, kuusen istutus, männyn kylvö

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Suonenjoki, January 2014

Ville Kankaanhuhta

LIST OF ORIGINAL ARTICLES

This thesis is a summary of the following articles, which are referred to in the text by their Roman numerals. The articles are reprinted with permission of the publishers.

I Kankaanhuhta V., Saksa T., Miina J. (2009). Quality management of forest regeneration service processes. In: Fournier M. (ed.). Forest regeneration: ecology, management and economics. Nova Science Publishers, Hauppauge, NY. p. 1–29.

II Kankaanhuhta V., Saksa T., Smolander H. (2009). Variation in the results of Norway spruce planting and Scots pine direct seeding in privately-owned forests in southern Finland. Silva Fennica 43(1): 51–70. http://www.metla.fi/silvafennica/full/sf43/sf431051.pdf

III Kankaanhuhta V., Saksa T. (2013). Cost–quality relationship of Norway spruce planting and Scots pine direct seeding in privately owned forests in southern Finland. Scandinavian Journal of Forest Research 28: 481–492. http://dx.doi.org/10.1080/02827581.2013.773065

IV Kankaanhuhta V., Saksa T., Smolander H. (2010). The effect of quality management on forest regeneration activities in privately-owned forests in southern Finland. Silva Fennica 44(2): 341–361. http://www.metla.fi/silvafennica/full/sf44/sf442341.pdf

Ville Kankaanhuhta has been responsible for planning the research and analysing the study material. In addition, he has been in charge of writing the articles. The above-mentioned co-authors have provided valuable comments and proposals for improvement of the articles. The quality control inventory method and the numerical definitions for the quality of forest regeneration have been inspired by M.Sc. Fred Kalland from the UPM-Kymmene Corporation and further developed by Saksa and Smolander (Saksa et al. 2005).

TABLE OF CONTENTS

ABBREVIATIONS

AAA	Assessment–Algorithm–Action sequence of a process or a process step
ABC	Activity-Based Costing
ANOVA	Analysis of Variance
FOA	Forest Owners' Association
CEO	Chief Executive Officer
GLMM	Generalised Linear Mixed Model
Good areas	Inventoried forest regeneration areas with good results
ICC	Intra Class Correlation
Inverting	Making a mound on a mineral soil mounding pit with a single humus layer
LMM	Linear Mixed Model
ML	Maximum Likelihood
Mounding	Mounding with ditching
MQL	Marginal Quasi-Likelihood
NIPF owner	Non-industrial private forest owner
Patching	Removal of the humus layer in patches
Patch mound(ing)	Upturned humus forming a flat mound with a double humus layer
PQL	Penalised Quasi-Likelihood
REML	Restricted Maximum Likelihood
RIGLS	Restricted Iterative Generalised Least Squares
Spot mound(ing)	Upturned humus forming a flat mound with a double humus layer
SPC	Statistical Process Control
TBC	Time-Based Competition
TQM	Total Quality Management
VPC	Variance Partition Coefficient

1 INTRODUCTION

Management has been defined at a general level as the achievement of goals through facilitating an effective process of planning, organising, leading, controlling and staffing (Fayol 1930, James 1996). At the highest level management is about creating policy, objectives and strategies based on the prevailing values and common vision (Juran and Gryna 1993, James 1996). The major problem in the implementation of several management practices has been the lack of careful thinking about the nature and purpose of the activities (Lillrank 1999). In addition, information regarding the performance of the activities is often lacking (Sarala and Sarala 1999). However, this would be essential in the analysis of the present state, which would support the decision making in the planning of business, public sector and politics at the national, European and international levels. What cannot be properly defined cannot be measured, and what cannot be measured cannot be managed. This is also the case in managing forest regeneration activities at various levels and time frames all the way from the strategic and tactical to operational level (Speidel 1972, Hasenauer 2006, Kangas et al. 2008).

The purpose of data acquisition and modelling for decision making may be classified as, e.g., scenario studies of silviculture, updating of forest stand information, updating of larger assessment units, instruction and control, professional training, and research (Pretzsch et al. 2006). In the case of forest regeneration, the three alternative sources for data acquisition used in modelling have been controlled regeneration experiments, collection of regeneration data as part of a routine forest inventory, and operational regeneration surveys or inventories (Miina et al. 2006). In Finland, the objectives of obtaining measured information and predicting the state of young stands have evolved during the past few decades. The first efforts aimed at defining good forest regeneration results, exploring the success of forest regeneration operations and factors influencing the consequent results were initiated in the 1960s in Finland. The main goals of the inventories conducted were to discover the practices applied in forest regeneration, results obtained using various methods, and possible future activities to ensure the further development of the stands (Yli-Vakkuri et al. 1969). In these inventories, the first definitions of “good-quality” forest regeneration results were established by means of determining the number of crop-trees and the proportion of treeless plots in the regeneration area. According to a study made by Yli-Vakkuri et al. (1969) and several subsequent regional surveys, the regeneration results were considered unsatisfactory (Räsänen et al. 1985).

The next major forest regeneration survey was conducted in Southern Finland on a proportion of the sample plots of the 7th National Forest Inventory at the end of 1970s (Räsänen et al. 1985). By then the need to coordinate information concerning the whole regeneration chain, including planning, execution, control and further development of silvicultural activities, had increased so that optimised decisions could be made. However, there was still insufficient information about the effectiveness of regeneration methods. The emphasis was on gaining a general view of the regeneration results at the regional level and not on the variation in the results between the actors. The regeneration results were considered better than ten years previously, but the selection of the regeneration method as well as the execution of the operations was considered variable and often inadequate (Räsänen et al. 1985).

In the beginning of 1980s, Räsänen (1981) first defined the forest regeneration process with the concepts of systems theory. He considered the growth of seedlings as the biological sub-process, and the human actions as technological sub-process with economical constraints, which could be improved by means of systems engineering. The systems approach is also valid from the viewpoint of this thesis. The chain of forest regeneration actions may be considered as a production process, the outcome of which is observed as a whole. Räsänen (1981) defined a "good young stand" as a fully stocked, healthy, well-growing stand, which has been established without any delays and at a reasonable cost.

Compared to the 1970s, the proportion of soil preparation applied within the context of artificial regeneration increased in the 1980s (Finnish Statistical … 2007). Another big change in the 1980s was the adoption of containerised seedlings (Rikala 2000, Finnish Statistical … 2007). The largest annual planting areas were attained in the 1980s (Finnish Statistical … 2007). Scots pine still dominated in artificial regeneration. The largest inventory studies were conducted by Kinnunen (1993), concentrating on Scots pine direct seeding and natural regeneration in Western Finland. Emphasis was placed on finding appropriate growing sites, soil preparation and regeneration methods for Scots pine (Kinnunen 1993). Saksa (1992), for his part, concentrated on Scot pine planting in Central and Eastern Finland. His main emphasis was on discovering appropriate soil preparation methods, growing sites and the magnitude of naturally regenerated supplementary seedlings in Scots pine planting areas (Saksa 1992).

In the 1990s, several changes in the operational environment of the forest regeneration service providers occurred. The objectives and activities of the operative actors were influenced, for example, by the changing legislation and norms, requirements for biodiversity, economic depression, structural changes in rural areas, and changing objectives of forest owners (Luonnonläheinen metsänhoito … 1994, Saksa and Smolander 1998, Saksa et al. 1999, Karppinen et al. 2002, Karppinen 2005, Niskanen et al. 2008). The proportion of cutting areas aimed at either natural regeneration or direct seeding increased compared to the 1980s (Finnish Statistical … 2007). At the same time, the proportion of planting areas decreased. There were also reports of delays in regeneration activities in several instances in the mid-1990s (Hartikainen and Kokkonen 1996, Saksa 1998).

In an international context, the structure of forest ownership is the starting point for the research of management frameworks for silvicultural service operations since it may be assumed to influence both activities in forestry and wood production (Leppänen and Nouro 2006). Non-industrial private forest (NIPF) owners hold 60% of Finnish forest-land and own 64% of the growing stock (Finnish Statistical … 2008). The average size of these forest property entities is 30 ha (Finnish Statistical … 2012). At the turn of the millennium, NIPF owners were automatically included as members of the local Forest Owners' Association (FOA), and they had to pay the statutory fee of silviculture to their FOA through the taxation system (Forest management … 1998). At that time, there were many municipalities in Finland where the local FOA was the main, and often only, provider of silvicultural services for NIPF owners. However, some new service providers were entering the market, and the above-mentioned monopolistic transaction context began to change gradually.

In Sweden, NIPF owners possess 50% of forest-land, and the average size of the forest holdings is almost 50 ha (Swedish Statistical … 2013). There are approx. twice as many NIPF owners in Finland as in Sweden. The average area of forest holdings has decreased in Finland, but increased in Sweden (Leppänen and Nouro 2006). Roughly half of all Swedish

NIPF owners belong to one of four regional forestry cooperatives, which have been named as FOAs (Kittredge 2003, Swedish Statistical … 2013). The forestry sector and wood markets have been considered to be more market oriented in Sweden than in Finland (Leppänen and Nouro 2006). The statutory fee of silviculture and subsidies for wood production were eliminated already in the beginning of 1990s in order to promote market driven improvement of silviculture (Statistical Yearbook … 1994, Rådström and Thorsén 2006, Swedish Statistical … 2013). In addition, further efforts have been directed to promote private forestry entrepreneurship, e.g., through changes in regulations and taxation (Leppänen and Nouro 2006, Rådström and Thorsén 2006). Methods of forest regeneration were fairly similar in Finland and Sweden at the turn of the millennium. However, direct seeding has been more common in Finland, whereas in Sweden, natural regeneration has been used instead (Finnish Statistical … 2012, Swedish Statistical … 2013).

There are wide regional variations in forest ownership between and within nations in North America (The North American … 2012). In the USA, approx. 38% of the nation's forest-land is owned by NIPF owners, 18% by private corporations while the remainder is under public ownership (Smith et al. 2009). Public forests dominate in the Western states while private forests are dominant in the Eastern states (Butler and Leatherberry 2004, The North American … 2012). Two-thirds of the privately-owned forest-land is owned by people or organisations with 40 or more hectares (Smith et al. 2009). In NIPFs, the incentive programs have shifted from tree planting and wood production toward sustainable forest management, environmental services, and preservation of natural capital (Moulton 1998, Moulton and Hernandez 2000, Peter et al. 2006, Jacobson et al. 2009a, 2009b). Furthermore, indirect incentives – e.g., technical assistance, management planning, and education – have been emphasised (Kilgore et al. 2007). In the case of Canada, nearly 93% of the forests are public, but the management of large forest areas and the usage of these resources are licensed to private forest companies (Peter et al. 2006, The state of Canada's … 2011, The North American … 2012). In New Zealand, over 90% of radiata pine (*Pinus radiata* D. Don) plantations are grown by either private companies or individuals (Mead 2013). Large growers manage 80% of the plantation area, and the average size of over 40 ha plantations is nearly 800 ha (National exotic … 2012). Since the mid-1980s, New Zealand has strived for an open economy and relatively little government involvement in promoting forestry (Mead 2013).

In the Finnish context at the turn of the millennium, several signals spurred the need for increasing the cost-efficiency of silviculture (Harstela et al. 2001). For instance, the trend of unit costs for silvicultural operations was upwards, whereas the corresponding trend in wood procurement had been downwards since the middle of the 1980s (Finnish Statistical … 2007). Furthermore, shortage of forest labourers was estimated to materialize by the end of the 2010s (Työvoiman saatavuus … 2005, Niskanen et al. 2008, Juntunen 2013). The structure of forest ownership (e.g., more pensioners, city dwellers and women) was changing so that the demand for highly-developed services would be increasing as opposed to self-service (Hänninen et al. 2011). Furthermore, the proportion of public subsidies for forestry was predicted to decrease most probably due to the weakening dependency ratio (Niskanen et al. 2008).

Quality management was one of the most potential solutions for answering the anticipated challenges in the non-industrial privately-owned forests of Finland (Harstela et al. 2001, Kalland 2002, Saksa et al. 2002, Kalland 2004, Saksa et al. 2005, Kiljunen 2006). For instance, the management systems of the industrially-owned forests faced a similar change of operational environment compared with the non-industrial privately-owned forests. In the case of UPM-Kymmene Corporation, the hierarchical organisational structures were flattened and local operative actors were empowered to make decisions and take responsibility for their actions (Kalland 2002, 2004). Strict instructions and manuals were replaced with a guidebook, which explained the principles behind reaching the "good-quality" targets. The quality management system created emphasised the activity of local actors in terms of three main elements: 1) agreement on clear objectives and definitions; 2) knowledge of key factors leading to success; and 3) objectively measured and analysed feedback on their own working performance (Kalland 2002). In 2004, with 10 years of experience and an inventory coverage of 40 000 ha, the inventory tool that was developed to measure forest regeneration results had evolved as a cost-efficient and effective part of the quality management system (Kalland 2004). Through this system, UPM-Kymmene was able to manage the quality of operations and simultaneously consider other objectives related to forestry.

In the international context, some quality control systems have been developed mainly for state-owned forests, and for large forest holdings, which may buy regeneration services from sub-contractors in free markets. In New Zealand and Australia, a system of quality assurance indicator plots, wall charts and checklists has been used in the planting of radiata pine in order to control seedling quality and planting operations (Trewin 2000, 2001, Mead 2013). In North America, quality inspection surveys using either circular sample plots or 10-tree rows have been applied in the quality monitoring of planting crews (Long 1991, Londo and Dicke 2006, Landis et al. 2010, Planting quality … 2012). In NIPFs of Sweden, forestry cooperative Södra has been developing self-control measurements for their sub-contractors (Petersson 2008, 2010a, 2010b). In addition to UPM Kymmene Corporation, other management frameworks have been integrated with quality management systems also in other forest industry companies (Kalland 2002, Hannus 1994). For example, J.D. Irving, which operates in the USA and Canada, has adopted a quality management system that has been subordinated to the principles of Supply Chain Management, Lean and Six sigma (Womack et al. 1990, Oakland 2003, J.D. Irving Northern … 2010).

Encouraged by the good experience from UPM-Kymmene's management system, a quality control inventory method and a system for quality management were proposed to be developed for the context of non-industrial privately-owned forests in Finland. The Finnish Forest Research Institute began developing the inventory method together with volunteering FOAs within the area of six forestry centres. Forestry centres were responsible for the sustainable management and use of forests at the regional level; the maintenance of their diversity; other tasks related to the promotion of forestry; control of the compliance with forestry legislation; and management of public authority tasks (Act on … 1995). The implementation of the quality control inventories revealed significant statistical variation in the regeneration results between the FOAs, which led to the development of a framework of quality management and interventions for forest regeneration quality management.

The starting point for further developing the framework of quality management for non-industrial privately-owned forests was the role of measured information in the planning, control, and improvement of forest regeneration activities together with the forest owners. In quality management, it has been emphasised that the decision making should be based on collected and analysed information including, e.g., customer needs, operational problems, and the success of improvement attempts (Malcom Baldridge … 2009). Quality management literature suggests that the organisations consistently collecting and analysing information will be more successful than those who do not (Dean and Bowen 1994). As demonstrated in the case study of the UPM-Kymmene Corporation, there will be a hypothetical potential for improving the results and quality of the local regeneration activities by means of increasing the quantity of measured feedback for the stakeholders at various levels.

The control of statistical variation and continuous improvement of the activities in supplier–customer chains have been considered as some of the main elements in quality management (Juran 1951, Deming 1986, Lillrank 2003a). Furthermore, experience in various fields of business has shown that the achievement of better quality does not necessarily require much higher costs (Crosby 1979, Gryna 1988a, Feigenbaum 1991). Success in reducing deficiencies through quality improvement is a form of cost reduction that, in turn, improves cost-efficiency, which stems from accumulation of experience with the production activities and economies of scale (Gale and Branch 1982, Phillips et al. 1983, Garvin 1988). Finally, more information concerning the feasibility of this management framework in the context of professional services for forest regeneration in the non-industrial privately-owned forests was considered necessary.

2 OBJECTIVES

The purpose of this thesis was to study the opportunities to improve the outcomes of forest regeneration activities through quality management. The main elements described by the founding authors of quality management were used as a general theoretical framework for this thesis. Since the context of forest regeneration services in non-industrial privately-owned forest in Finland differs from those fields of business where quality management has been found to be most effective, the classification of service processes from standard, through routine to non-routine, was chosen as a starting point for the framework to be developed (Lillrank 2003a). The main emphasis was on finding out how the quality of forest regeneration activities could be most feasibly managed in the non-industrial privately-owned forests in Finland.

The aim of Article I was to introduce a framework on how to model and improve forest regeneration service processes with respect to three main goals. Specifically, the first goal was to provide the concepts and terminology of quality management in order to be able to measure and control various kinds of forest regeneration service processes, either internal or external. The second goal was to introduce the conceptual methods regarding how to model and set performance indicators for the actions of forest regeneration. The third goal was then to demonstrate how the theory of quality management could be applied to improve forest regeneration activities.

In the context of forest regeneration services, especially the control of statistical variation in the results of activities was hypothesised to be a noteworthy issue. The general aim of Article II was to reveal the magnitudes of statistical variation caused by the main factors influencing Norway spruce planting and Scots pine direct seeding results in order to develop the framework further. The first goal was to examine the results of Norway spruce planting and Scots pine direct seeding, unveil the variation between the different FOAs and the extent to which the variation in regeneration results could be explained in terms of both regional and administrative levels and also ecological factors. The second goal was then to determine the ecological and operational factors, which would explain the regeneration outcome.

In Article III, the general aim was to demonstrate the improvement opportunities for cost-efficiency and quality of forest regeneration services. The purpose of this case study was to reveal the cost–quality relationship of forest regeneration services taking the main local factors – i.e., site fertility type, soil texture type, soil stoniness and wetness – into account together with differences between municipalities. Specifically, the first goal was to determine the overall correlations between the costs and outcomes of regeneration activities at both the regeneration area and municipal levels. Next, it was studied whether the hypothesised factors influenced the results of regeneration activities in order to provide a comparable starting point for cost-quality analysis. The third goal was then to elucidate the cost–quality relationships of Norway spruce planting and Scots pine direct seeding. Additionally, the goal was to ascertain whether some of the hypothetical factors had been taken into account in the selection of methods and implementation, and whether this was observable in the cost of regeneration.

The aim of Article IV was then to evaluate the effect of quality management interventions on the FOAs' forest regeneration actions with respect to four principal goals. First, what was the obtained feedback from the educational sessions for determining the root causes of the results and what were the objectives that were set? Second, what quality management tools had been adopted and what were the changes in available resources for performing forest regeneration activities? Third, what forest regeneration practices were adopted in the FOAs? And fourth, what were the level of knowledge and attitudes of the actors?

3 THEORETICAL FRAMEWORK

3.1 Operational environment of forest regeneration services

In the non-industrial privately-owned forests (NIPF) of Finland, forest regeneration services are one of the major services of the Forest Owners' Associations (Finnish Statistical … 2004, 2007, 2008). At the turn of the millennium, the transaction context had to be considered monopolistic and the statutory fee of silviculture distorted the competition in the service markets (Forest Management … 1998, Viitala 2006). In many municipalities, the service concepts of the local small FOAs were still at the level of craft-like practices, however, without need for cost-efficiency and quality (Harstela et al. 2001, Kiljunen 2006, Viitala 2006).

In the markets of forest regeneration services of a certain municipality, the NIPF owners may expect the FOA to provide some or all of the following services: soil preparation work; regeneration material, i.e., seedlings or seed; and regeneration work. The forest owner may also prefer a certain kind of soil preparation method or regeneration material, which differs from the recommendations of the forestry professional. In the ideal case, the recommendations of the skilled forestry professional are taken into account as the service product is defined. As shown in Figure 1, the forest regeneration service process may be classified as an open system, which is influenced by its operational environment and requirements of the client (Bhaskar 1975, Danermark et al. 2002). In order to construct a framework for quality management of forest regeneration services, this open service system was tentatively split into four sub-systems: 1) marketing of the regeneration methods and tree species; 2) soil preparation; 3) choice of regeneration material; and 4) regeneration work.

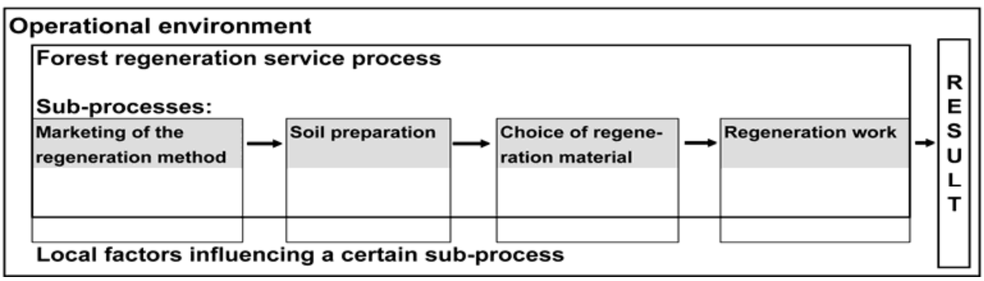

Figure 1. Forest regeneration service process is classified as an open system. The system is influenced by various factors of the operational environment. In addition, the sub-systems may be influenced by various factors depending on the local circumstances and natural conditions.

The forest owners' values, attitudes and objectives of forest ownership influence the co-creation of the service product (Karppinen et al. 2002, Karppinen 2005). Legislation and norms as well as local environmental conditions – e.g., weather, soil conditions and seed years – limit the varieties of service products (Karppinen 2005). The requirements of stakeholders, those of biodiversity, prevailing economic situation in addition to local organisational structures probably influence both the customers and forestry professionals (Metsäkeskus Tapio 1994, Saksa et al. 1999, Viitala 2006). Additionally, the resources available – e.g., labour, machines and regeneration material – influence the results of forest regeneration activities.

3.2 Quality management as a proposed solution

Service operations management has been defined as the implementation of the organisation's strategy through the operational control of the organisation by focusing not only on the product or service development, but also on the delivery of these service products to the end-customer in a way that it drives co-creation of value between customer and business (McLaughlin 2010). In short, service has been defined as value co-creation (Spohrer and Maglio 2010). The value created has been described as the change that stakeholders prefer and realise as a result of communication, planning, and other purposeful as well as knowledge-intensive interactions. In operations management, one of the key phenomena to be explored is why one operation – factory or service unit – is superior to others according to the measures defined (Schemenner and Swink 1998). The productivity – output per input resources – may be regarded as one of the key measures (Schmenner and Swink 1998, Spohrer and Maglio 2010).

Service operations consist of front-office and back-office activities (i.e., processes), the former of which is visible to the customer (McLaughlin 2010). The productivity of service processes may be studied from three different perspectives (Grönroos and Ojasalo 2004). Service providers usually have certain processes that are executed in isolation. These back-office processes may not differ considerably compared with the production of goods, and their productivity may be improved according to various models of operations management for manufacturing of goods (Schwenner and Swink 1998, Lillrank 1999). As services are co-created with the customer, there may also be some processes that are carried out in isolation by the customer (Gummesson 1998, Grönroos and Ojasalo 2004). The relationship between the service provider's inputs and outputs may be analysed under the concept of internal efficiency (cost efficiency); and if required, the investments in the education of the customer may be included (Grönroos 2010). In the case of forest regeneration services, e.g., the planting work may be carried out by the forest owner, who is guided towards the best practices. Finally, there are interactive service processes, the outcome and productivity of which are influenced by both the service provider and the customer (Gummesson 1998). These interactive service processes co-produce outputs, the quantity and quality of which are components of external efficiency (Grönroos and Ojasalo 2004).

The quality of the service process output is defined under the construct of customer-perceived quality (Grönroos 1982, 1998, 2001, 2010). Perceived quality is determined by the technical quality of the outcome and functional interaction-induced quality dimensions, which are filtered through the image of the service provider in the customer's mind (Grönroos 1982, 1998, Grönroos and Ojasalo 2004). The previously-mentioned construct is to a considerable degree consistent with Lillrank's (2010) classification of four types of quality. At the lowest level, the resource and time consumption of the process with standard output may be studied under the concept of process quality. At the next level, the actual output of the process may be analysed through comparing the deviations from given targets. This concept of technical quality may be judged according to the conformance to agreed standards (Lillrank 2010). Respectively, Crosby's (1979) definition of quality was "*Conformance to requirements*". Deming's (1986) proposal for the definition of quality was a little broader: "*Quality should be aimed at the needs of the consumer, present and future.*" Juran (1988a), on his behalf, elegantly defined quality as "*Fitness for use*". Furthermore, Garvin (1984, 1988) has proposed an eight-dimensional construct for defining both technical and perceived quality. In conclusion, one way to improve the efficiency of the back-office service operations is to improve process quality and technical quality.

In the context of those service processes, in which the involvement of both service provider and customer are required, the level of mutual understanding and agreement may be evaluated through the concept of interactive quality (Lillrank 2010). In short, interactive quality may be defined as the fulfilment of requirements and expectations. It refers to the service provider's ability to assess various situations and adjust the routines with the aim of achieving the expected outcome. Errors in the interpretation and classification of inputs may lead to poor quality outcomes. Interactive quality is a measure of service process effectiveness. Finally, at the highest level, customer-perceived quality of the service may be evaluated. It is defined as the experiences of a customer in relation to expectations (Lillrank 2010). Customer-perceived quality may be measured quantitatively through attribute-based models, or qualitatively, e.g., by means of favourable and unfavourable service incidents (Parasuraman et al. 1998, Zeithaml et al. 2009, Grönroos 2010).

In the context of the productivity of service operations, there are five interrelated dimensions in operations management: cost, quality, dependability, speed, and flexibility (Ferdows and DeMeyer 1990, Gummesson 1998, Schmenner and Swink 1998, Slack et al. 2010). Depending on the line of business, the significance of these objectives varies. However, they are all relevant from the viewpoint of internal and external efficiency. All of the other previously-mentioned objectives influence the cost of service processes (Ferdows and DeMeyer 1990). In addition, the lower the cost of co-producing the services, the lower the price can be for the customer. In the case of not-for-profit organisations, low costs of operations give good value for tax payers and cost advantage for service providers (Slack et al. 2010). Quality, on its behalf, means consistent production of services, which satisfies the external customers and enhances customer retention (Deming 1986, 1994, Taguchi 1986, Juran 1988b, Gummesson 1998, Slack et al. 2010). Good technical quality means reduced costs for inspection, less rework and waste of materials, lower need for long-term maintenance, less complaints, and reduced risk for lost sales (Crosby 1979, Gryna 1988a, Feigenbaum 1991, Atkinson et al. 1994, Dale and Plunkett 1995, Campanella 1999). Furthermore, good quality increases dependability of operations, which means stable and predictable processes. Total Quality Management (TQM) has been regarded as the main management framework, which is based on assumptions about the importance of quality (Savolainen 1997, Lillrank 1999, Slack et al. 2010).

The dependability objective of service operations will considerably influence customer retention and the customer's image of the reliability of the service provider (Gummesson 1998, Slack et al. 2010). If the services are not provided as promised – e.g., on schedule – satisfaction with low price and fast execution will be overridden. From the viewpoint of internal operations, predictability of quality attributes and reliable timing save overall time resources, and costs (Ferdows and DeMeyer 1990). For example, supply chain management may be used to manage the entire value chain from the providers or materials and other resources all the way to the end customer (Christopher 1998, Ballou 2004, Slack et al. 2010). This framework manages all the activities including customer relationship management, procuring of appropriate materials, obtaining resources, planning and scheduling of operations as well as distribution management and logistics.

Time has been considered as a competitive weapon, which is equivalent to cost and quality (Stalk 1998, Stalk and Hout 1990). Time-Based Competition (TBC) has been defined as the pursuit of competitive advantage by speed (Lillrank 1995). TBC is a management framework developed from some elements of Japanese Lean Production and observations of the competitive behaviour of some Japanese companies (Lillrank 1995, Womack et al. 1990). Lean Production is most applicable in high-volume mass production with a moderate variety of models and functions in fairly predictable environments, which are more or less closed systems (Christopher 2000). It benefits from high quality of production and it reduces costs (Lillrank 1995). The speed of service operations means shorter time elapsed between customers requesting these products and receiving them (Stalk 1988, Slack et al. 2010). Fast service operations save the customers' time and resources, minimise unproductive state of belongings, and may even secure the state of health (Kujala et al. 2006, Slack et al. 2010, Voehl and Elshennawy 2010). In the back-office operations, fast service processes decrease the level of in-process inventories and perishable materials, speed up the movement of information, reduce the risks in long-term decision making, and decreases administrative overheads. In addition to TBC, a viewpoint of bottlenecks in operations (Theory of constraints) may also be applied in the improvement of the swift even flow of information and materials (Schmenner and Swink 1998, Goldratt and Cox 2004). Time-Based Competition has later been adopted by other management frameworks – e.g., Business Process Re-Engineering – which redesign the organisations and processes as well as utilise the opportunities provided by information and communications technology (Hammer and Champy 1993, Davenport 1993, Lillrank 1995).

In order to become more responsive to the needs of the customers, something more than speed is required (Christopher 2000). Flexible service operations adapt quickly to changing circumstances and unpredictable demand without unnecessarily hampering other production activities (Slack et al. 2010). Flexibility may be manifested in the ability to introduce new or modified services; in the ability to produce a wide range or mix of varieties; in the ability to adjust production volumes; and, in the ability to change the timing and scheduling of the service products (Takeuchi and Nonaka 1986, Naylor et al. 1999, Christopher 2000, Agarwal et al. 2007). Depending on the line of business, flexibility may be pursued through mass customisation or Agile management (Boynton et al. 1993, Pine 1993, DaSilveira et al. 2001, Slack et al. 2010). Agility may be regarded as a combination of quality, dependability, speed, and flexibility (Naylor et al. 1999, Slack et al. 2010). Agility has been defined as responding to market requirements by producing new and existing products and services fast and flexibly (Slack et al. 2010). Flexibility in internal service operations speeds up the response times, saves time for both customers and service providers, and maintains dependability of the service processes.

Depending on the line of business and operational environment, different management frameworks may be applied to emphasise the desired performance dimensions – quality, dependability, speed, and flexibility. Considering the challenges observed in the context of forest regeneration services in the NIPF of Finland, TQM (later also referred to quality management) was chosen as the starting point. Furthermore, as it was assumed that if these performance dimensions were pursued in the previously-mentioned sequence, they would most probably facilitate the improvement of other dimensions and adoption of more advanced management frameworks, e.g., time-based management or lean management, and agile management (Ferdows and DeMeyer 1990, Schmenner and Swink 1998, Slack et al 2010). A similar kind of sequential transformation has also been proposed from continuous improvement of processes (process enhancement) through mass customisation to co-configuration of production processes (Boynton et al. 1993, Pine 1993, Victor and Boynton 1998).

Total Quality Management (TQM) has been defined as a management doctrine or ideology that is based on assumptions about the importance of quality, which has been considered important from the viewpoint of competitiveness (Savolainen 1997, Lillrank 1999). TQM has been named as a shorthand expression for the "quality disciplines" that are applied to all functions and levels of organisation in a coordinated way (Juran 1996). The origin of TQM is in the Japanese industrial practices that were heavily influenced by Walter A. Shewhart, W. Edwards Deming and Joseph M. Juran (Shewhart 1931, Juran 1951, Ishikawa 1985, Deming 1986, Garvin 1988). Garvin (1988) has provided an overview of the development of quality management from inspection, through statistical quality control and quality assurance to strategic quality management, which may also be called Total Quality Management. TQM has been defined by means of contemporary practical models: the standards of ISO 9000 series and quality awards, such as Malcom Baldridge National Quality Award (MBNQA), European Quality Award and Japanese Deming Prize (Dean and Bowen 1994, Juran 1996, Lillrank 1999, Kujala 2002, Malcolm Baldridge…2009). In this thesis, the theory of TQM has been approached by the common assumptions and principles of the main authors of TQM, e.g., Deming, Juran and Ishikawa (Ishikawa 1985, Deming 1986, Juran 1989, Deming 1994, Hackman and Wageman 1995).

3.3 Main elements of quality management

Quality management has been regarded as an organisational innovation that has contributed a scientifically grounded methodology to deal with defects in mass-manufactured products and high-volume services (Lillrank 2003b). The foundation for quality and productivity improvements has been concentration on the standardising of work processes, analysis of uncontrolled statistical variation, utilisation of the systematically measured data, and learning from the results of continuous improvement (Deming 1986, Ishikawa 1985, Juran and Gryna 1993). Other important principles have been defined as emphasis on customer satisfaction and participative management practices, especially teamwork (Juran and Gryna 1993, Dean and Bowen 1994, Oakland 1994). These factors emphasise the integration of technology in production and the contributions of the behavioural sciences (Baker 1988, McGregor and Cutcher-Gershenfeld 2006). In the following, these elements are summarised according to the System of Profound Knowledge proposed by Deming (1994) and Gitlow (2001).

In quality management, organisations are viewed as systems that consist of highly interdependent functional components – i.e., processes – which have the common aim (Deming 1994, Hackman and Wageman 1995). The effectiveness of each functional component depends on how it fits into the whole and the effectiveness of the whole system depends on the way each component functions together (Churchman et al. 1957). An entire organisation may be defined as a network of people in supplier (producer) – customer (user) relationships or quality chains (Baker 1988, Oakland 1994). If every component or sub-process of the system only optimises its own performance, the performance of the whole organisation, as well as the satisfaction of external customer, will be compromised (Deming 1986, Ishikawa 1985, Baker 1988). On the other hand, despite the systemic nature of the organisations and production systems, it is not self-evident that the management systems have to be comprehensive systems (Lillrank 1999).

The quality of commodities depends on the processes by which they are designed and produced (Ishikawa 1985, Deming 1986, Juran 1992). Juran (1992) defines a process as "*a systematic series of actions directed to the achievement of a goal*". A process may also be defined as "*a transformation of a set of inputs, which can include actions, methods and operations, into outputs that satisfy customer needs and expectations, in the form of products, information, services or –generally – results*" (Oakland 1994). A process may have resources – people, equipment and knowledge – as fixed assets, inputs as variable assets, and services as output (Lillrank 2003a). A process may be part of a large system and may also have one or several layers of sub-processes as shown in Figure 1.

The understanding of statistical variation of different varieties of deliverables has been proposed as another fundamental element for quality management (Deming 1986, 1994, Lillrank 2003a). In general, variation may be considered as an expression of difference between targets and actual output. On the other hand, variety has been defined as a set of different targets that are functionally equivalent within a given price range (Lillrank 2003b). Variety should not be confused with different products or performance levels that are not real alternatives for a customer (Lillrank 2003a). In the case of forest regeneration activities, variation describes a measurable deviation from the previously defined target – e.g., the number of planted seedlings per ha, or the proportion of good regeneration areas per service provider. The level of quality has been proposed to "*start with marketing*" (Oakland 1994), which means genuine dialogue between the supplier and customer. The forestry professional should be able to meet the requirements of the forest owner. On the other hand, the service provider should inform the client, if the commodity does not fit for the client or it is impossible to produce.

While the concept of variety represents different targets that offer alternative ways to satisfy the same need of the forest owner, variation exhibits the imperfections of the service provider's endeavours. Thus, in the inputs, actions and output of the production processes, uncontrolled variation has been regarded as the primary cause of quality problems (Hackman and Wageman 1995). Deming (1986, 1994) stated that one of the main challenges of management was the understanding of variation and obtaining the information it contained. The key element in improving production processes has been the removal of the causes of variation. In Article I, the classification of statistical variation into assignable (special) causes and common (random) causes are discussed (Shewhart 1931, Deming 1986, Oakland 2003). In the context of forest regeneration activities, the issue of the causes of variation will be essential (Articles II and III).

Continuous improvement has provided an effective way of learning and gaining knowledge to improve the production processes in clearly defined and controlled conditions (Ishikawa 1985, Deming 1986, Baker 1988, Gryna 1988b, Deming 1994). The idea for continuous improvement of production processes was established in the 1930s by Walter Shewhart (1931), who proposed that when formulating the right kind of hypothesis and applying statistical methods, it was possible to eliminate the special causes of variation and obtain a stable state for the process with only the common causes of variation present. This framework for process management – specify, produce, inspect – was equivalent to the scientific method of acquiring new knowledge (hypothetic–deductive reasoning): hypothesise, experiment and test the hypothesis (Baker 1988, Deming 1994, Gitlow 2001). In the 1950s, W. Edwards Deming developed this idea further, and introduced it to the Japanese industry in the form of "Plan – Do – Check – Act" (PDCA) -cycle (Ishikawa 1985, Deming 1986). In the organisational learning theory, this corresponds to single-loop learning (Argyris and Schön 1978). Respectively, double-loop learning occurs when defects and errors are corrected in ways that involve the modification of an organisation's underlying norms, policies and objectives.

Behavioural sciences provide a means for understanding the interactions between the people and production systems, which provide an opportunity for greater organisational efficiency and effectiveness (Baker 1988, Deming 1994, Gitlow 2001). In general, the main authors of quality management agree with Maslow's (1943) theory of human motivation and McGregor's Theory Y about management and the employees' attitudes towards work (Ishikawa 1985, Deming 1986, Baker 1988, Hackman and Wageman 1995, McGregor and Cutcher-Gerschenfeld 2006). It is assumed that people are naturally proud of their workmanship, care about the quality of their work, and take initiatives to improve their actions (Deming 1986, McGregor and Cutcher-Gershenfeld 2006). For instance, Baker (1988) provides examples of those elements in work that motivate people to expend effort and try to improve according to Maslow's theory of motivation.

3.4 Classification of processes

Most of the classical and technical literature of quality management deals with repetitive processes of mass manufacturing (Shewhart 1931, Deming 1986, Ishikawa 1985, Juran 1992, Oakland 2003). Standardisation of the processes yields the greatest opportunities for the improvement of cost-efficiency, predictability and control over the processes. The implementation of quality management in areas where the assumptions of standardised mass manufacturing or high-volume services are not valid have been considered challenging (Silvestro 2001, Lillrank 2003b). These kinds of services are usually professional services with low volume and high variety, where the rate of customisation or case sensitivity is high (Silvestro 2001, Lillrank 2003b). These services have typically non-routine processes, unpredictable environments, controversial objectives, and may involve non-market transactions (Lillrank 2003a, 2003b). Processes form a continuum from highly standardised processes of mass manufacturing through routine processes to non-routine service processes, which may have controversial objectives and unpredictable operational environments (Lillrank 2003a, 2003b). Complicated processes may be combinations of sub-processes, which may consist of different types of the above-mentioned processes.

At a general level, a process can be defined as a transformation of a set of inputs, which can include actions, methods and operations, into outputs. A process has three distinct phases that may be referred to as the "Assessment–Algorithm–Action" (AAA) sequence. In the first phase, the situation, including the inputs, is 'assessed'. Next, the 'algorithms' defined for the process generate control information. Finally, 'actions' based on the control information are carried out. The quality of an AAA -sequence may be analysed by applying the following concepts: target, tolerance, variation and variety (Shewhart 1931, Taguchi 1986, Oakland 2003). The inputs and outputs of the process may be given acceptance criteria, which are in relation to predetermined targets. The variation in the inputs and resources of the process, as well as in the transformation, produces variation to the output (Oakland 2003). The technically and economically tolerated proportion of variation has to be defined with tolerance zones for inputs and outputs (Shewhart 1931, Taguchi 1986, Oakland 2003).

In target-oriented production processes, the concepts of variation and variety have fundamentally different meanings (Taguchi 1986). Variation is referred to as a measurable deviation from the predefined targets (Shewhart 1931, Deming 1986, Taguchi 1986, Deming 1994). Variety, on the other hand, is known as a set of different targets or products that are functionally equivalent; they offer different ways to fulfil the same need of the customer (Taguchi 1986, Lillrank 2003a). The standard, routine and non-routine processes differ in the way how the AAA sequence is structured in terms of variation and variety. In Article I, examples and implications for managing these types of processes are provided.

In the case of a standard process, single varieties are accepted for inputs, and a single variety output has been set for a target. First, in the assessment phase, the acceptance test of the inputs is based on binary logic – the input variety is either accepted or rejected. The conversion rules are then defined by standardised algorithms in the conversion phase. Standard processes are repeated identically thousands of times. This is also known as 'mindless repetition following scripts'. Even in a standard process, variation cannot be completely known and controllable. Standardised processes may, however, be designed to relatively closed systems, which produce products with low risk.

Routine processes accept a limited set of varieties as input and they have a limited set of target varieties for outputs. First, the input variety is assessed through classification, which applies fuzzy logic or tacit knowledge. In the case of appropriate characteristics or 'pigeonhole', the input for the process is accepted. Next, in the algorithm phase, the conversion rules are defined by a repertoire of response algorithms, grammatical rules, or habits. In an ideal case, the routine process assesses input conditions, and applies the most suitable algorithm that is quite formalised and standardised. Routine processes are typically repeated similarly, but not identically. Finally, as the action phase has been initiated, the output of the process can be predicted reasonably well. It is, however, possible that the inputs and the repertoire of actions that follow do not match. This causes the process to slip into a non-routine mode.

Non-routine processes accept an unspecified set of relevant input varieties and they have a set of viable target varieties for outputs. First, at the assessment phase, the set of input varieties may be larger than the bounded rationality or experience set employed by the process. The assessment of the input variety is based on interpretation and assigned meaning in attempt to develop new algorithms and actions. In the algorithm phase, the conversion rules are then defined by heuristics, which may require a search for new inputs as well as several iterations of trial and error. For the most part, non-routine processes are non-repetitive open systems, which operate at a relatively high risk. In the case of a non-routine process, the accomplishment of a task is many times more important than the pre-defined output.

3.5 Methodology

In this thesis, quality management is mainly studied in a specific and limited scope, in which sources of statistical variation and effect of quality management interventions are explored. These types of applications of quality management lead to objectively measurable results, and cause-effect relationships and mechanisms between events can be defined (Kujala 2002). The construction of a framework for quality management of forest regeneration activities follows a combined four-step pattern of causal analysis and theory development proposed by Bhaskar (1975) and Tuomivaara et al. (1994). First, the events (i.e., forest regeneration activities) are resolved into components. In practice, this means the description of the forest regeneration activity system (service process), which consists of a set of sub-systems or sub-processes. Furthermore, the environment of the system and the relationships between the sub-systems are conceptually described. In the second step, the components obtained are theoretically re-described so that their inner constitution is revealed. In other words, these components are modelled into the conceptual model of forest regeneration service processes according to the theoretical framework of quality management (Article I). Furthermore the theory of data generation is constructed simultaneously for the preparation of the statistical analysis (Tuomivaara et al. 1994).

In the third step, the models are developed further through the exploration of simple causal and stochastic links using both induction and hypothetic–deductive reasoning. The statistical generalisability is assessed for Articles II, III and IV (Yin 1994, Perry et al. 1999). Furthermore, possible causes for the events in certain circumstances are retroduced (Bhaskar 1975, Tsoukas 1989, Danermark et al. 2002). Some examples of these are presented in Articles I–III, and in Article IV, which provides information on the effect of quality management interventions.

In the fourth step, the system dynamics are explored. This means that comparisons between hypothetical mechanisms – e.g., feedback loops – in different conditions are made (Bhaskar 1975, Bunge 2004). A special case explanation for certain specified conditions is created through elimination of alternative causes. As a result, an analytical generalisation of the findings is made (Yin 1994, Perry et al. 1999). Furthermore, the mechanisms found are concretised and contextualised. On the whole, the framework constructed for quality management of forest regeneration will be a tentative one. Therefore, it has to be verified, tested, evaluated and further developed in the future.

4 MATERIAL AND METHODS

4.1 Conceptual modelling of forest regeneration service processes

The standard, routine and non-routine processes may be analysed through the AAA sequences of these processes (Article I). In practice, this means studying the acceptance criteria of the inputs, viewing the type of assessment, exploring the rules of conversion in the algorithm phase, and analysing the type of repetition and logic (Lillrank 2003a). The classification of the processes differs in the way the AAA sequence (assessment, algorithm, action) is structured in terms of variation and variety. This has profound implications for the management of various types of processes based on several factors (Lillrank 2003a). Including, for instance, the tools available for controlling the service processes, the production of good-quality outputs in respect to occurrence of defects and errors, and the type of learning that occurs and is required to manage processes. Finally, it will be essential to recognise, what the required improvement methodologies are. Better control over the various types of processes as well as economic cost-efficiency may be achieved by means of exploiting existing experience and scientific knowledge, experimentation and learning.

From the viewpoint of modelling, the design, analysis and continuous improvement of production or service processes may require modelling at conceptual, quantifiable, and dynamic levels. In the beginning, forest regeneration activities are resolved into components and re-described resulting in conceptual models, which are also known as constructs. At this level, for example, the essential actions and responsibilities as well as different performance indicators for the control of the service process are defined. Next, simple causal and stochastic links are explored through quantifiable models for static points in time. Gradually, the emphasis shifts towards dynamics, in which feedback loops and decision support are considered. In some fields of business – e.g., mass-produced goods and chemicals – genuine quantitative dynamic models may be created. However, the requirements for the accuracy of the key indicators or parameters, not to mention the controllability of the production system, are high. Because of this, many lines of business (e.g., services) are not able to exploit these models thoroughly.

In the conceptual modelling of forest regeneration service processes, the level of details in descriptions was chosen so that the systemic features of the activities were verifiable. This conceptual model was constructed by triangulating information from four main sources (Tashakkori and Teddlie 1998, Creswell 2003). First, the results of experimental and inventory studies concerning forest regeneration and related fields were exploited. Second, the information from the registries and databases of FOAs were collected and investigated (e.g., information on timing, types of seed, methods and execution of operations). Third, the descriptions and flowcharts of forest regeneration services created in the quality management interventions of the "Forest regeneration quality management" project were examined (Saksa and Kankaanhuhta 2007). Fourth, specific details about the prevailing forest regeneration practices were collected during interviews with the chief executive officers (CEOs) of the FOAs for the educational events dealing with quality management techniques. Altogether 12 CEOs of the FOAs, which participated in the study about the cost–quality relationship of Norway spruce planting and Scots pine direct seeding, were interviewed (Tables 1 and 2).

Table 1. Norway spruce planting – annual coverage of inventoried forestry centres, FOAs, and municipalities ("Inv. tw." refers to the number of municipalities inventoried twice).

Forestry	FOAs	Munici-	Inv.	Inventory year (ha)						Forestry centre	
centre[a)]		palities	tw.	2000	2001	2002	2004	2005	2006	area, ha	%
L-S	2	4	0	0	0	11	0	56	0	67	8
H-U	1	4	2	0	0	45	0	0	141	187	22
E-S	3	3	3	0	19	92	0	38	45	194	23
E-P	1	1	0	0	0	0	0	34	0	34	4
P-S	3	4	3	109	87	0	29	140	0	366	43
Total	10	16	8	109	107	148	29	268	187	847	
%				13	13	17	3	32	22		100

[a)] Abbreviations for forestry centres: L-S = Lounais-Suomi, H-U = Häme-Uusimaa, E-S = Etelä-Savo, E-P = Etelä-Pohjanmaa, P-S = Pohjois-Savo.

Table 2. Scots pine direct seeding – annual coverage of inventoried forestry centres, FOAs, and municipalities ("Inv. tw." refers to the number of municipalities inventoried twice).

Forestry	FOAs	Munici-	Inv.	Inventory year (ha)						Forestry centre	
centre[a)]		palities	tw.	2000	2001	2002	2004	2005	2006	area, ha	%
L-S	2	6	2	0	0	161	0	55	0	216	16
H-U	1	1	1	0	0	20	0	0	14	34	2
E-S	3	3	1	0	0	60	0	33	44	136	10
E-P	3	5	3	0	219	242	0	193	161	815	60
P-S	3	3	0	45	118	0	0	0	0	163	12
Total	12	18	7	45	336	482	0	280	218	1362	
%				3	25	35	0	21	16		100

[a)] Abbreviations for forestry centres: L-S = Lounais-Suomi, H-U = Häme-Uusimaa, E-S = Etelä-Savo, E-P = Etelä-Pohjanmaa, P-S = Pohjois-Savo.

The interviews of CEOs were carried out by means of semi-structured interviews from three to five years after the first quality control inventories. The topics covered the main actions of the hypothetical regeneration process. For openers, the current practices and tentative efforts for improvements after the first inventories were discussed. Next, the prevailing distribution of labour, organisation and timing of operations, and rules for responsibilities were covered in the questions. Marketing of the regeneration chains was then discussed including the costs and pricing of services, information content of the service-related negotiations as well as possible collection of feedback from customers. The selection of appropriate tree species and methods for regeneration were discussed in connection with marketing. The sources of information – forest management plans and on-site inspection of site properties by forestry professionals or soil preparation operators – were discussed in the context of recommendations for the forest owner. Additionally, the autonomous decisions by forest owners deviating from the recommendations by management plans or forestry professionals were reviewed.

The soil preparation activities including selection of methods, planning and scheduling, implementation and evaluation of operations were explored. Furthermore, conceptions of CEOs regarding the knowledge and skills of machine operators as well as needs for instructions and training were touched. Next, the selection and supply chains of regeneration material were explored. In the case of seedlings, the questions covered the types and quantities of seedling material, number and quality of suppliers, organising of operations, instructions, acceptance control of seedlings, storage, maintenance and evaluation procedures for seedling vitality. Correspondingly, in the case of seed material, the questions covered the types and quantities of seed and likewise the suppliers.

The regeneration work was then discussed. In the case of direct seeding, the grounds for the timing, methods and quantities selected were explored after the implementation of the operation by machine contractors or manual workers, who were either professionals or private forest owners. The local trends in the proportions of regeneration methods applied were also evaluated. In the case of planting operations, planning and organising of labour resources were explored. In addition, the instructions for permanent and temporary workers as well as for active private forest owners were discussed including target densities, implementation and evaluation of work. The final topic dealt with the local service development activities for forest regeneration, silviculture and other forest services.

4.2 Quality control inventory method

The theory of data acquisition as concerns the results of forest regeneration activities has evolved over the decades (e.g., Yli-Vakkuri et al. 1969, Pohtila 1977, Pohtila 1980, Räsänen et al. 1985, Eid et al. 1986, Saksa 1992, Kinnunen 1993, Kalland 2002). The performance variables for the inventories have been selected according to the results of both experiments and inventory studies. In the 1990s, the first streamlined operational inventory methods for monitoring the quality of forest regeneration results actualised in the forests of forest industry companies (Hämäläinen and Räsänen 1993, Kalland 2002). In the beginning of 2000s, the development of operational quality control inventories was initiated for non-industrial privately-owned forests (Saksa et al. 2002, Saksa et al. 2005).

The most common regeneration chains applied in Finland, i.e., planting of Norway spruce and direct seeding of Scots pine, were selected for this study. The planted areas were inventoried at the age of three, and the directly seeded ones at the age of four years. At this stage, the quality achieved could be seen to result from regeneration operations. In addition, the development of sprouts and broadleaves had not yet significantly disturbed the results. The inventories were carried out in the area of six forestry centres in Southern Finland – Lounais-Suomi, Häme-Uusimaa, Etelä-Savo, Etelä-Pohjanmaa, Keski-Suomi, and Pohjois-Savo (Figure 2). The regeneration results were inventoried from the years 2000 to 2006. In the case of Norway spruce planting, the corresponding planting years were 1997–2003, and those of Scots pine direct seeding were 1996–2002.

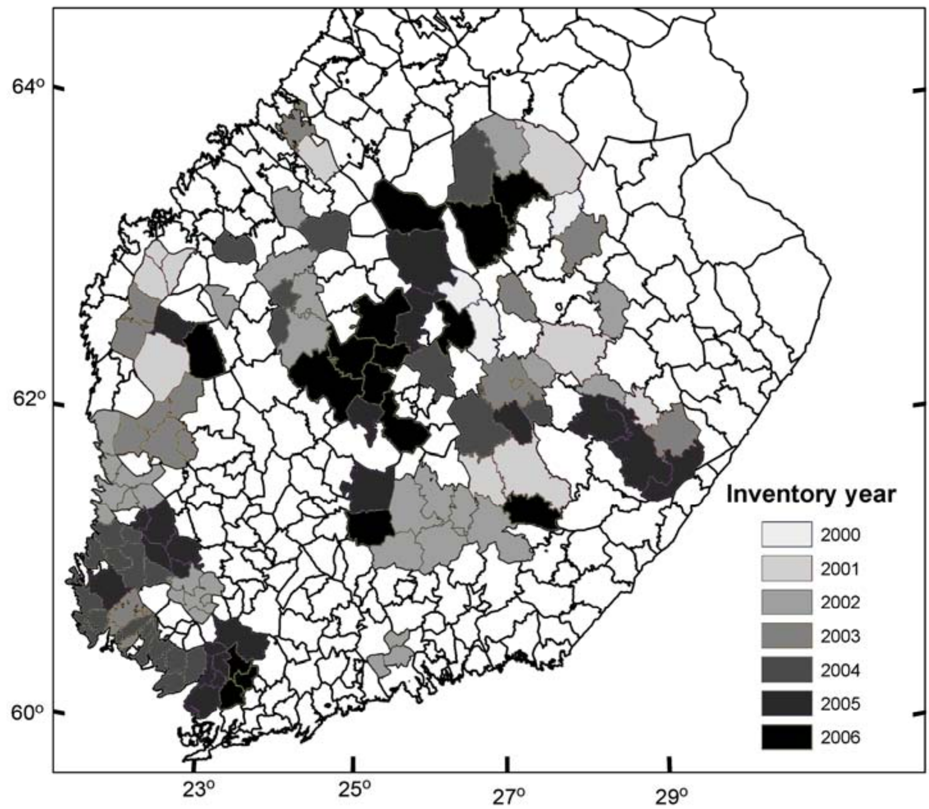

Figure 2. Coverage of forest regeneration quality control inventories in 2000–2006. Some of the municipalities were inventoried twice. The first inventory year is shown in the map. (Copyright of the map layer and borders of the municipalities: Maanmittauslaitos, lupanro MYY/179/06-V).

The FOAs in the above-mentioned forestry centres participated in the inventories and quality work voluntarily so as to improve their forest regeneration activities. They were not chosen randomly. The FOAs covered from one to more than ten municipalities, and some of those were inventoried twice. During the first inventory round, the entire extent of regeneration areas within the chosen municipalities belonging to an FOA was recommended to be inventoried. The background information on the regeneration areas (later also referred to as stands) was collected from the registries of FOAs and later verified during the course of the inventories. The variables recorded for the stand level were: identification information; year of regeneration cutting, soil preparation, and regeneration work; the size of the regeneration area; the type of seedling material; and, executor of the regeneration work (FOA or private forest owner). The seedling material was classified as small containerised (one-year-old), large containerised (1.5-year and older), or bare-root seedlings. The main criteria for including a stand in this study were that the main method of regeneration was either Norway spruce planting or Scots pine direct seeding.

The result of forest regeneration operations was measured through application of a systematic regular-shaped sampling grid. Areas of 0.5–2.0 ha were measured using 15 circular sample plots that spanned 20 m^2 (radius 2.52 m). For regeneration areas 10 ha or larger, an extra sample plot was measured for each area of half a hectare. In the case of Norway spruce planting, the number of seedlings planted, crop-trees and trees in total were recorded by tree species. A crop-tree was defined as a seedling with sufficient vigour and quality for timber production. The number of crop-trees consisted of planted seedlings and supplementary conifer seedlings. The size prerequisite for a naturally regenerated crop-tree was that its height was >50% of seedlings planted. In addition, the minimum distance between crop-trees recorded was one metre, and their maximum number was set at six crop-trees per sample plot (3000 crop-trees per ha). In those rare cases where the number of planted seedlings was greater, they were all counted. The above-mentioned criteria were set in order to sort out the clustering effect of seedlings at the sample plot and regeneration area levels (Pohtila 1980).

The total number of seedlings was recorded in the context of both Norway spruce planting and Scots pine direct seeding. The total number of seedlings was counted by tree species for Scots pine, Norway spruce, seedling-origin birches, and other broadleaves, including sprout-origin birches. The seedlings counted were expected to be healthy, at minimum 5 cm in height, and the distance between seedlings had to exceed 30 cm. The maximum number of seedlings recorded was set at 20 per sample plot even though more seedlings existed. In the context of Scots pine direct seeding, the total number of Scots pine seedlings was used for evaluation of the regeneration result. The total number of pine seedlings included both sown and naturally regenerated ones.

The variables recorded during the quality control inventories at the sample plot level were site type, soil type, soil preparation method, regeneration method, and target tree species. Furthermore, any wetness that might weaken the regeneration result and the degree of stoniness preventing soil preparation were recorded. The model of site type classification created by Cajander (1926, 1949) was applied: *Oxalis-Maianthemum* type (OMaT), very rich; *Oxalis-Myrtillus* type (OMT), rich; *Myrtillus* type (MT), damp; *Vaccinium* type (VT), sub-dry; *Calluna* type (CT), dry; and *Cladonia* type (ClT), barren. For peatlands, the same main classes (very rich, rich etc.) were used in accordance with the work of Laine and Vasander (1990). The soil was classified as coarse, medium or fine mineral soil, or as a peat layer thicker than 20 cm. The method of soil preparation was classified as disc trenching, patching, mounding, no preparation, or other. The regeneration method recorded included information, e.g., about planting, manual or mechanised sowing. In association with mechanised sowing, disc trenching was mostly used. However, excavator-based sowing equipment was also used in some FOAs.

The information concerning the variation in the results of regeneration activities may be used at different levels for several purposes including simple feedback to local forestry professionals, design and improvement of service processes by the local service provider, support of the activities by extension education officers at the forestry centres, or research. For the quality work with the local forestry professionals and FOAs, target densities were defined for different regeneration chains. These target densities were also utilised in Article III (Cost–quality relationship of forest regeneration activities). In the case of Norway spruce planting, the definition used for a good regeneration result at stand level was 1600 conifer crop-trees per ha. This target density was selected for three main reasons. First, at the end of the 1990s, when the first regeneration activities were carried out, the recommended planting densities varied from 1400 to 1800 seedlings per ha

(Luonnonläheinen metsänhoito … 1994). Therefore, the average target density was chosen. Second, a certain proportion of mortality was presumed to emerge. Third, the supplementary deciduous seedlings were not classified as crop-trees at this early stage of the stand (Saksa et al. 2005). In the case of Scots pine direct seeding, a good regeneration result was defined as 3000 pine seedlings per ha at stand level. The number of pine seedlings consisted of both sown and naturally regenerated ones. This target density was chosen to promote growing of saw timber of good technical quality (Varmola 1996).

In the feedback meetings of quality control inventories, and in the quality work in general, the results of regeneration activities were analysed at both the sample plot and stand levels. The variables at the sample plot level were also generalised at stand level in Article III (Cost–quality relationship of forest regeneration activities). If a certain variable class (e.g., site type class MT) covered 50% or more of the sample plots, the site type of the stand would be classified as MT. In the case of soil wetness or stoniness, a threshold value of 30% was used.

4.3 Variation in the results of forest regeneration

4.3.1 Description of data

The data set of Norway spruce planting covered 8557 ha in the area of six forestry centres (Table 3), and the average size of the regeneration areas was 1.8 ha. The data set consisted of material from 4879 regeneration areas containing 77 989 sample plots. The dominant site type was MT with a proportion of 70% of the sample plots. Patching was the most commonly applied method of site preparation (42%). Medium coarse mineral soil covered nearly two-thirds of the sample plots inventoried. Both soil stoniness and wetness accounted for approximately three per cent of the sample plots. The most common classes of variables recorded were used as a reference class in further analysis. In the modelling of Norway spruce planting, the dependent variable was the number of planted seedlings at the sample plot level. The average number was 2.8 seedlings per plot (SD = 1.5 seedlings per plot). In addition, there were 0.7 supplementary conifer crop-trees per plot (SD = 1.1 crop-trees per plot).

The data set of Scots pine direct seeding covered 4948 ha, and the average size of the regeneration area was 2.0 ha. The data set consisted of 2447 regeneration areas that included 39 523 sample plots. The dominant site type was MT representing 46% of the sample plots. Disc trenching was most frequently used for site preparation (77%), and mechanised sowing prevailed (58%). Medium coarse mineral soil was the most common soil type (64%). Stoniness accounted for approx. seven per cent and soil wetness approx. five per cent of the sample plots. The most common classes of variables inventoried were used in the modelling. In the case of Scots pine direct seeding, the dependent variable of the model consisted of the total number of Scots pine seedlings, which were either sown or naturally regenerated. The average number of Scots pine seedlings was 6.2 per sample plot (SD = 5.2 seedlings per sample plot).

Table 3. Yearly inventories at different forestry centres.

Forestry centre		Inventory year							Total
		2000	2001	2002	2003	2004	2005	2006	
Norway spruce planting									
Lounais-Suomi	area, ha	0	0	104	63	235	319	99	819
	% of total	0	0	1	1	3	4	1	10
Häme-Uusimaa	area, ha	0	0	275	0	0	0	545	820
	% of total	0	0	3	0	0	0	6	10
Etelä-Savo	area, ha	0	140	327	323	272	613	240	1915
	% of total	0	2	4	4	3	7	3	22
Etelä-Pohjanmaa	area, ha	0	25	61	70	102	180	121	560
	% of total	0	0	1	1	1	2	1	7
Keski-Suomi	area, ha	0	0	0	0	223	330	525	1079
	% of total	0	0	0	0	3	4	6	13
Pohjois-Savo	area, ha	488	521	475	429	450	417	585	3365
	% of total	6	6	6	5	5	5	7	39
Grand total	area, ha	488	687	1241	885	1282	1860	2116	8557
	% of total	6	8	15	10	15	22	25	100
Scots pine direct seeding									
Lounais-Suomi	area, ha	0	0	254	255	133	197	56	894
	% of total	0	0	5	5	3	4	1	18
Häme-Uusimaa	area, ha	0	0	66	0	0	0	95	160
	% of total	0	0	1	0	0	0	2	3
Etelä-Savo	area, ha	0	22	126	38	173	209	98	665
	% of total	0	0	3	1	3	4	2	13
Etelä-Pohjanmaa	area, ha	0	380	523	72	635	329	457	2396
	% of total	0	8	11	1	13	7	9	48
Keski-Suomi	area, ha	0	0	0	0	16	89	126	231
	% of total	0	0	0	0	0	2	3	5
Pohjois-Savo	area, ha	92	149	58	10	152	44	97	601
	% of total	2	3	1	0	3	1	2	12
Grand total	area, ha	92	552	1026	375	1108	867	928	4948
	% of total	2	11	21	8	22	18	19	100

4.3.2 Analysis methods

The analysis of the variation in the regeneration results consisted of separate models for Norway spruce planting and Scots pine direct seeding. In the model for planting of Norway spruce, the response variable was the number of planted seedlings per 20 m^2 sample plot. In the model for direct seeding of Scots pine, the response variable was the total number of pine seedlings per sample plot. The structure of the data was hierarchical, and consequently multilevel or mixed modelling was applied (Goldstein 1996, Snijders and Bosker 1999). There was a five-level nested hierarchy in the data (Table 4): forestry centre, FOA, forestry professional, stand, and plot. At the different levels of the hierarchy, the observations may be more or less correlated. Because of this, random effects have to be added to the model in order to tackle the variation at different levels. As a result, a variance component model is created, where a variation of the intercept is permitted across the levels (Snijders and Bosker 1999).

The proportion of variation explained by the above-mentioned hierarchical levels was modelled using normal multilevel or Linear Mixed Models (LMMs). LMMs were chosen because the calculation of the variation explained was not possible in the Poisson-distributed Generalised Linear Mixed Models (GLMMs). This was due to the fact that at the lowest level (sample plot) of the hierarchy, the scale of the variance component was different compared to the upper levels. Two LMMs were created for both of the regeneration chains in order to find the difference between the empty model and the one with significant fixed parameters. The significance of the parameter estimates included was checked. However, the actual estimates of the various factors influencing the result of regeneration were made in GLMMs described later in this chapter. The general form of the LMMs applied was:

$$y_{mlkji} = x'_{mlkji}\beta + u_m + u_{ml} + u_{mlk} + u_{mlkj} + \varepsilon_{mlkji}\,, \tag{1}$$

where y is the number of seedlings, x' is a vector of fixed predictors, and β is a vector of the fixed parameters. The subscript i refers to a plot, j to a stand, k to a forestry professional, l to a FOA and m to a forestry centre. The u_m, u_{ml}, u_{mlk} and u_{mlkj} are random effects that denote: forestry centre, FOA, forestry professional and stand levels. The ε_{mlkji} is the normally distributed residual or error term at the plot level. Respectively, σ_m^2, σ_{ml}^2, σ_{mlk}^2, σ_{mlkj}^2 and σ_ε^2 are between-FOAs, between-forestry professionals, between-stands, and within-stand or -plot level variances. The previously-described model without fixed parameters may also be called a variance components model due to the fact that the variance is divided into components corresponding to each level of the hierarchy. The proportion of total residual variation refers to either the Intra Class Correlation (ICC) or Variance Partition Coefficient (VPC) (Rasbash et al. 2004). The ICC has two definitions: 1) the correlation between two randomly drawn units in one randomly drawn group; or 2) the proportion of total variability that can be attributed to the differences between groups (Rasbash et al. 2004, Snijders and Bosker 1999).

The following example demonstrates how the proportion of variation (ρ_{MLK}), which can be attributed to differences between forestry professionals (u_{ml}) working in FOAs (u_{ml}) in the domain of forestry centres (u_m), may be calculated:

$$\rho_{MLK}(Y) = \frac{\sigma_m^2 + \sigma_{ml}^2 + \sigma_{mlk}^2}{(\sigma_m^2 + \sigma_{ml}^2 + \sigma_{mlk}^2 + \sigma_{mlkj}^2 + \varepsilon_{mlkji}^2)} \tag{2}$$

Table 4. Number of hierarchical units in Norway spruce planting and Scots pine direct seeding.

Class variable	Norway spruce planting				Scots pine direct seeding			
	No. of units	Units in one upper class			No. of units	Units in one upper class		
		Mean	Min	Max		Mean	Min	Max
Forestry center	6				6			
FOA	41	7	2	10	39	7	2	10
Forestry professional	284	7	1	21	228	6	1	15
Municipalities[a)]	119				112			
Regeneration areas	4879	17	1	140	2447	11	1	88
Sample plots	77989	16	10	36	39523	16	10	29

[a)] Forestry professionals may work in the area of several municipalities: in Norway spruce planting 10% and in Scots pine direct seeding data set 19%. On the other hand they may work only in a part of a municipality, which would give the model a crossed structure.

The variance partition coefficients were estimated using the restricted maximum likelihood (REML) method both in SAS/STAT 9.1.3 PROC MIXED and in MLwiN 2.02 (RIGLS) (SAS Institute Inc. 2004, Rasbash et al. 2004).

The multilevel models describing the factors influencing the regeneration result were constructed as GLMMs. The response variables (i.e., seedlings at sample plot level) were count data. Consequently, GLMMs containing assumptions of Poisson distribution were used in the final models (McCullagh and Nelder 1989, McCullogh and Searle 2001). Poisson models with log-link functions have also been applied by Wilson and Maguire (1996), Hyppönen et al. (2005), Miina and Saksa (2006), and Miina and Saksa (2008). The general form of the Poisson-distributed GLMMs was:

$$\begin{aligned} & y_{mlkji} \sim \text{Poisson}(\pi_{mlkji}), \\ & g(\pi_{mlkji}) = \eta_{mlkji} = f(X,\beta) + u_m + u_{ml} + u_{mlk} + u_{mlkj}, \end{aligned} \tag{3}$$

where y is the dependent variable (i.e., the number of seedlings), $g(.)$ is a log-link function, η_{mlkji} is the linear predictor, $f(.)$ is the fixed part of the model, X is a vector of the fixed predictors, and β is a vector of the fixed parameters. The subscript i refers to a plot, j to a stand, k to a forestry professional, l to an FOA, and m to a forestry centre. The u_m, u_{ml}, u_{mlk} and u_{mlkj} are random effects that denote forestry centre, FOA, forestry professional and stand levels. The random effects have a zero mean and are normally distributed with constant variances. The random terms are assumed to be uncorrelated across the levels.

A Poisson-distributed response variable y with a mean π also has a variance of π (Rasbash et al. 2004). Depending on the phenomenon, however, there may be more or less variation, i.e., var(e_{mlkji}) (McCullagh and Nelder 1989, Goldstein 1996). If the data exhibits either more or less variation than the Poisson distribution, extra variation may be taken into account. More variation in the data is referred to as over-dispersion, whereas less variation is known as under-dispersion. Planted seedlings are usually evenly distributed in the regeneration area so that under-dispersion may occur. On the other hand, directly-seeded and natural seedlings are typically more clustered, which may result in over-dispersion.

The extra Poisson variation was taken into account by allowing either under- or over-dispersion of the response variables. Penalised Quasi-Likelihood (PQL) with 2nd order Taylor series expansion was applied, since 1st order PQL and MQL methods tend to overestimate some of the variance parameters (Goldstein 1996, Rasbash et al. 2004). In addition, McCullogh and Searle (2001) have made the same observations. MLwiN 2.02 software was used in fitting the models (Rasbash et al. 2004). Furthermore, the results were compared with estimates fitted using the R package version 2.5.1 applying 1st order PQL (glmmPQL), since 2nd order PQL was not available (Venables and Ripley 2002). Candidate models were evaluated predominantly by means of Wald tests, in conformity with earlier results of research and likelihood information, where available. Residual checks were applied at various hierarchical levels as well as with the fixed variables.

4.4 Cost–quality relationship of forest regeneration activities

4.4.1 Collection of cost data

The cost data included only the regeneration areas that were entirely implemented by the FOAs. The cost data collected for the planted stands consisted of soil preparation, planting work, supervision, and other unclassified costs. Furthermore, the number and type of seedlings documented in the charges as having been delivered and planted were recorded. The cost data collected for the sown stands included soil preparation, seed, sowing work, and other costs. In addition, the quantity of seed was recorded from the registries of the FOAs.

The cost information collected, excluding value added tax, was imported into the same database as the inventory data. The wholesale price index was applied in order to adjust the annual variation of the costs to the level of the year 2003, which was the last regeneration year included in the data set. The years of implementation recorded for different actions (e.g., soil preparation, planting work) of regeneration services were applied to the costs of actions separately. In the case of Norway spruce planting, the primary criteria applied for selecting inventoried stands for further analysis were that the soil preparation, planting work and seedling costs should be available. In the case of Scots pine direct seeding, the principal criteria were soil preparation and seed costs since the sowing work was frequently included in the soil preparation costs. The cost class of the sowing work predominantly revealed the proportion of manual sowing applied, for in the case of mechanised sowing the soil preparation and sowing work were typically charged for together. The result of regeneration activities and the cost of the services were calculated for each regeneration area. In addition, the area-weighted averages were calculated for comparison of the cost of regeneration with the proportions of well-regenerated stands at the municipal level.

4.4.2 Description of inventory data

The data set of Norway spruce planting consisted of 16 municipalities belonging to 10 FOAs (Table 1). The data set consisted of 409 regeneration areas covering 847 ha. Three-fourths of the total surface area was situated in those municipalities, which were inventoried twice. This amounted to half of the total number of municipalities. The average size of the stands inventoried was 2.1 ha. Quality control inventories covered at least 10 ha or six stands per year. The most common site type was MT (75%) and the soil texture type medium coarse mineral soil (68%). The dominant method of soil preparation was patching (47%), and the seedlings delivered were typically 1.5 years or older (69%). Stands characterised by wetness and stoniness were in the minority.

The dependent variables for the models of Norway spruce planting were the number of planted seedlings (per ha), the number of naturally regenerated supplementary seedlings (per ha), and the cost of regeneration activities at the stand level. The average number of seedlings planted was 1499 per ha (SD = 360 seedlings per ha); the average number of naturally regenerated supplementary seedlings was 324 per ha (SD = 271 seedlings per ha); and, the average cost of regeneration activities 854€ per ha (SD = 167€ per ha). The number of seedlings charged as having been delivered and planted in the regeneration areas was recorded from the registries of FOAs. The average number of seedlings charged was 1717 per ha (SD = 274 seedlings per ha).

The data set of Scots pine direct seeding consisted of 18 municipalities belonging to 12 FOAs (Table 2). The data set consisted of 593 regeneration areas covering 1362 ha. The average size of the stands inventoried was 2.3 ha. Two-thirds of the land area covered was located in those municipalities inventoried twice. This area accounted for two-fifths of the total number of municipalities. The dominant site type was VT (46%) and the soil texture type medium coarse mineral soil (71%). Disc trenching was the most frequently used method of soil preparation (91%), and the majority of sowing was mechanised (80%). Soil stoniness (8%) and wetness (5%) were noted in a few regeneration areas.

The dependent variables in Scots pine direct seeding models were the total number of pine seedlings (seedlings per ha) and the cost of regeneration activities at the stand level. The average number of Scots pine seedlings was 3383 per ha (SD = 1786 seedlings per ha). The average cost of regeneration activities was 301€ per ha (SD = 46€ per ha). The average quantity of seed material charged for was 350 g per ha (SD = 96 g per ha).

4.4.3 Analysis methods

The analysis of the cost–quality relationship was initiated through calculating Pearson's product-moment correlation coefficients for the costs and number of seedlings both at stand and municipal levels (Zar 1996). The calculation of correlations between the costs and the proportion of well-regenerated stands then followed at the municipal level. Next, multilevel models were constructed for the cost–quality relationship of Norway spruce planting and Scots pine direct seeding to account for the hierarchical structure of the data (Goldstein 1996, Snijders and Bosker 1999). Finally, multivariate multilevel models were constructed in order to reveal the root causes behind the cost–quality relationships, i.e., the selection and implementation of regeneration methods.

The multilevel models were chosen due to the hierarchical structure of the data and the hypothesised intercorrelatedness of the response variables. In both multilevel- and multivariate multilevel models, the data were in a two-level hierarchy: regeneration areas (stands) within a municipality that were inventoried in a certain year. The primary purpose for the usage of inventory year was to technically separate the two inventory rounds in the municipality from each other. Municipality was chosen as the hierarchical unit for the second level instead of an FOA for three main reasons (Viitala 2006). First, each FOA had historically managed the area of one municipality, thus the non-industrial privately-owned forests automatically belonged to this area of jurisdiction. Second, different silvicultural fees have been set for different municipalities. Third, although mergers of FOAs began to intensify in the 1990s, the jurisdiction of the forestry professionals' teams and their management decisions remained relatively stable with respect to the borders of municipalities. In the municipalities of Article (III), the regeneration activities were still carried out by single municipality FOAs on approx. 60% of the land area. Additionally, the silvicultural fees were defined separately for each municipality in over three fourths of the area.

In the multilevel models constructed for describing the cost–quality relationship, the dependent variables were calculated at the stand level. The dependent variable for the model of Norway spruce planting was the number of crop-trees, which consisted of both planted seedlings and naturally regenerated supplementary conifer seedlings. These naturally regenerated seedlings were taken into account since they potentially influence the overall regeneration result. Respectively, the dependent variable for the model of Scots pine direct seeding was the total number of pine seedlings representing both sown and naturally regenerated ones.

In the case of the multivariate multilevel model for Norway spruce planting, the number of seedlings planted, the number of naturally regenerated supplementary conifer seedlings, and the cost of regeneration activities were used simultaneously as dependent variables. In the corresponding model for Scots pine direct seeding, the total number of pine seedlings and the cost of regeneration activities were modelled together. The previously mentioned numbers of seedlings inventoried in the sample plots were all calculated at stand level.

The relationship between the regeneration cost and results was modelled by fitting of normally distributed multilevel models:

$$y_{ji} = x'_{ji}\beta + u_j + \varepsilon_{ji} \ , \qquad (4)$$

where y is the regeneration cost or the number of seedlings, x' is a vector of fixed predictors, and β is a vector of fixed parameters. The most common values of the class variables were used as a reference class for fixed predictors. The subscript i refers to a regeneration area (or stand), and subscript j refers to a municipality that was inventoried in a certain year. The u_j is a random effect associated with the municipality, and ε_{ji} is the normally distributed residual error term at the stand level. Respectively, σ_j^2 and σ_ε^2 are municipal- and stand-level variances. A multilevel model without fixed parameters is also known as a variance components model, due to the fact that the variance is partitioned into components, which correspond to each level in the hierarchy (Rasbash et al. 2004). In the case of multivariate multilevel models, the simultaneous estimation of the response variables and recognition of their correlations improve the estimates (Goldstein 1996).

The multilevel multivariate models were estimated simultaneously applying the Restricted Iterative Generalised Least Squares (RIGLS) algorithm in MLwiN 2.20 software (Rasbash et al., 2004; Rasbash et al., 2009). Candidate models were evaluated predominantly by means of likelihood ratio and Wald tests using the χ^2 distribution and thereafter compared with previous research results. Residual checks were applied at both levels of hierarchy as well as with the fixed variables.

4.5 Effects of quality management interventions

4.5.1 Interventions and mail surveys

Forest regeneration quality management interventions consisted of field inventories, feedback meetings, and education sessions regarding quality management techniques. The interventions were carried out in the voluntary FOAs belonging to six forestry centres – Lounais-Suomi, Häme-Uusimaa, Etelä-Savo, Etelä-Pohjanmaa, Keski-Suomi, and Pohjois-Savo. The forestry professionals who had been working for these voluntary FOAs were named quality management participants or participant forestry professionals. The rest of the FOAs within the area of the above-mentioned forestry centres were regarded as 'control' FOAs, with no interventions. The forestry professionals in these 'control' FOAs were named non-participant forestry professionals.

The quality control inventories were conducted during early summer in the years 2000–2006. The feedback meetings dealing with the results of regeneration activities followed the next autumn. All of the forestry professionals employed by the participant FOAs were invited. In the meetings, root causes for the obtained results of inventories were provided. The analysis of the root causes exploited both the latest research knowledge on the best practices of forest regeneration and statistical analysis of the inventory data available. The meetings enabled pinpointing of the causes for the forest regeneration activity results since the participants were able to provide historical information about the practices that prevailed from three to five years before the inventories. In the feedback meetings, the participants were encouraged to explore the data obtained even more thoroughly and set targets for improvement activities.

Two kinds of education sessions were arranged at the forestry centre level. Education sessions dealing with principles of quality management and quality management techniques were arranged for the FOAs in Etelä-Savo, Etelä-Pohjanmaa, Lounais-Suomi, and Pohjois-Savo. In addition, education concerning local issues of forest regeneration – e.g., direct seeding or soil preparation – was arranged at the forestry centres. Furthermore, 11 of the participant FOAs engaged in a second inventory round. In the majority of these FOAs, extra activities of education dealing with the quality control of forest regeneration activities were provided. In the current research, these FOAs were generally treated as 'quality work participant' FOAs. However, if the results from these more experienced ones significantly deviated from those of 'one-inventory FOAs', these FOAs were reclassified as 'two-inventory FOAs'.

The research project 'Forest regeneration quality management' concluded at the end of the year 2006. In June 2007, the project report was sent to every FOA in Southern Finland (Saksa and Kankaanhuhta 2007). Two mail surveys were posted to the forestry professionals at the participant and non-participant FOAs. For the first mail survey, the response time was March–April 2006, and it was designated as '2006 survey' (Table 5). The second survey, which was labelled the '2007 survey', was posted in autumn 2007. The response time was scheduled for September–October 2007. In the both surveys, the questions asked were practically the same. They differed mainly in sample size, target group, and timing. The sample size for the 2006 survey was smaller, and it was directed only towards forestry professionals, rather than chief executive officers (CEOs). In addition, some of the FOAs had not yet participated in the inventories conducted in early summer of 2006. In this study, the 2006 survey has been used as a pilot survey and baseline for comparisons. The 2007 survey was conducted in order to obtain an overall image of the addressed research aims. As a prerequisite, a minimum of one growing season's time had to be available to initiate improvement efforts according to the feedback obtained from the inventories. For the most part, the results of the 2007 survey are covered in this thesis. However, whenever there are deviations in the results between the 2007 and 2006 surveys, the results of the 2006 survey are also presented.

The questionnaires were posted to all of the forestry professionals involved in the activities of forest regeneration in the area of six forestry centres. The CEOs of the FOAs were included in the sample of the 2007 survey. The control group consisted of all forestry professionals, both operative and CEOs, whose FOA had not participated in quality management interventions in the area of the aforementioned forestry centres. If only part of an FOA (e.g., one municipality out of several) was situated within the area of those six forestry centres, the forestry professionals of the municipality in question were included in the sample.

4.5.2 Description of data

In the 2006 survey, 303 forestry professionals comprised the original sample and the response rate was 64%. In total, there were responses from 65 FOAs with the average response rate for the main questions being 61%. The 2007 survey had an original sample size of 385 forestry professionals and the corresponding response rate was 54%. Responses arrived from 64 FOAs with the average response rate for the main questions being 52%. The sample size of the 2007 survey was 27% greater compared to the 2006 survey. The information obtained in the surveys at the municipal level was combined with information on forestry land coverage from the 9^{th} Finnish National Forest Inventory (NFI9). In the 2006 survey, the respondents represented 69% of the forestry land of the six forestry centres. In the case of the 2007 survey, the proportion of forestry land covered was 71%.

The CEOs of the FOAs may have specialised entirely in management activities or also had operative responsibility for, e.g., the silvicultural services. In total, 83% of the participant respondents in the 2007 survey had regeneration areas inventoried under their supervision. The CEOs accounted for 8% and 'normal' participant forestry professionals for 75% of these responses, respectively. Following the inventories, feedback meetings were held, in which 74% of the respondents participated.

The forestry professionals of the non-participant FOAs were enquired whether they had participated in any seminars or educational sessions concerned with quality management of forest regeneration. Seminar participation accounted for 74% of the responses in the survey of 2007. In addition to various educational sessions, professional newspapers and magazines were the most common sources of information. Other sources of information cited included books, Internet, colleagues, and internal development events arranged by the regional forest owners' unions.

The questionnaires of the 2006 and 2007 surveys focused on various aspects of the continuous improvement of the forest regeneration service process: resources, defined key performance indicators, state of activities, as well as attitudes and aspirations for the development of forest regeneration services. This information was for the most part measured by nominal scale variables. The target densities of seedlings planted and target quantities of seed material were measured as discrete, absolute scale variables. The completion time of direct seeding was an interval scale variable.

Table 5. The distribution of responses at forestry centre level. The proportions of forestry land in relation to the total area of the surveys applying the classification: participant, non-participant and no response (The 9th National Forest Inventory, municipal level data).

Survey year	Forestry centre [a)]	Quality work participation			Coverage of forestry land (NFI9)		
		Non-partici-pant, %	Partici-pant, %	Respon-ses, total	Non-partici-pant, %	Partici-pant, %	No res-ponse, %
2006	L-S	14	27	44	2	8	4
	H-U	42	8	37	7	3	3
	E-S	10	20	33	4	9	3
	E-P	16	19	35	4	10	7
	K-S	10	6	14	5	3	10
	P-S	8	20	31	4	10	4
	Total	100	100	194	26	43	31
2007	L-S	5	20	30	1	7	6
	H-U	31	9	36	6	3	4
	E-S	16	20	38	3	9	3
	E-P	29	19	47	6	10	6
	K-S	6	12	20	2	8	8
	P-S	13	20	35	4	12	2
	Total	100	100	206	22	49	29

[a)] Abbreviations for forestry centres: L-S = Lounais-Suomi, H-U = Häme-Uusimaa, E-S = Etelä-Savo, K-S = Keski-Suomi, E-P = Etelä-Pohjanmaa, P-S = Pohjois-Savo.

4.5.3 Analysis methods

In most of the analysis, conventional statistical methods were applied: sample means, cross-tabulations, χ^2 tests, and linear regression. In the case of Scot pine direct seeding, the quantities of seed per hectare were analysed by applying both ANOVA and LMMs. The LMMs were used to examine whether there was a hypothesised correlation between the forestry professionals working within the same forestry centre. In addition, there could also have been a potential correlation between the forestry professionals within the same FOA, but there were too few forestry professionals per FOA for this correlation structure to be applied with reasonable estimates (forestry centre, FOA, forestry professional). SPSS 15.0.1 software for Windows was used in the analysis. In the first phase, the model fit was tested using maximum likelihood (ML), and the final parameters were estimated using restricted maximum likelihood (REML). The fixed effects were tested using F-test statistics.

5 RESULTS

5.1 Conceptual model for managing forest regeneration processes

5.1.1 Marketing of the regeneration method

The service process of forest regeneration was tentatively split into four sub-processes in the beginning of this thesis (Figure 1). The service process begins with the marketing of regeneration methods and tree species. Soil preparation then follows. Next, the choice of regeneration material and consequent supply chain has to be managed. Finally, the regeneration work itself is carried out. During the research process the conceptual model was then tested and refined in cycles (Figure 3). Forest regeneration activities were analysed from the viewpoint of the Assessment–Algorithm–Action (AAA) sequence, and performance indicators were proposed for planning, controlling and improving the activities (Article I).

The forest regeneration service process is initiated as a forest owner contacts a forestry professional either before or after the final harvest. The first sub-process – marketing of the regeneration method – continues after the initial contact through assessment of site fertility and soil type information, which is acquired from either a forest management plan or field visit by the forestry professional, or both. The negotiation concerning the variety of the regeneration service product follows. There is a limited set of regeneration chains, which represent the different varieties of the forest regeneration service process, e.g., planting of Norway spruce, direct seeding of Scots pine, planting of silver birch (*Betula pendula* Roth.), or natural regeneration of Scots pine. From the forest owner's viewpoint, it is a moment of decision making, which is influenced by the attitudes, values and goals of forest ownership. At this stage, it is still undecided as to whether the regeneration activities become a routine or iterative non-routine process. All the varieties of the forest regeneration service product (i.e., combinations of tree species and methods of regeneration), however, do not suit for all forest owners under different environmental conditions and various circumstances.

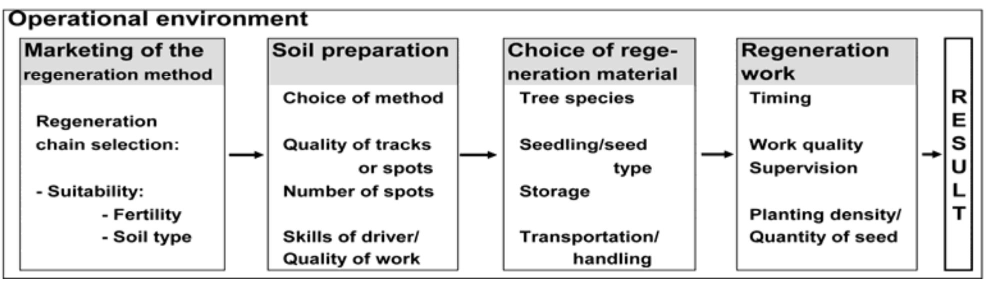

Figure 3. Forest regeneration service process and examples of performance indicators. The service process is classified as an open system that is influenced by various factors of the operational environment.

The results of the assessment phase in the marketing sub-process influence the next sub-processes. The most recommendable approach is to consider the relationship of the service provider and customer as a long-term value-adding partnership. If poor advice related to the suitability of a certain regeneration chain or method of regeneration action is provided, the reputation of the service provider will be weakened and future business opportunities may be lost. For example, the rationale of a forestry professional with a high-class performance was: "*A forestry professional should be welcomed to visit the forest owner also in the future*". Another statement from a well-performing forestry professional in regards to the rhetoric of the marketing negotiations was: "*Of course, if you (meaning the forest owner) want to do harm on your property, we will not prevent you…*" In general, it is recommendable that the forestry professional in charge should not promise such varieties of service products that cannot be provided with consistent quality.

In the partnership between the FOA and the forest owner, the key issue is how to establish a genuine dialogue, which aids co-creation of the required services. Since the knowledge level of the NIPF owners may vary to a great extent, the assessment phase of this sub-process is threefold. The forestry professional has to establish a common language with the client. Then, he has to obtain information on the level of knowledge, attitudes and skills of the client. Lastly, he has to gather information on the local site and soil conditions from the forest management planning system and preferably also by visiting the stand in person. For the majority of the cases, fitting varieties of service (chains of regeneration) may be offered. The actual measured quality control information about the success of various methods in local conditions may prove to be a valuable asset. However, it is possibilite to slip into a non-routine mode, which requires double-loop learning, i.e., questioning the prevailing norms and paradigms for service provision (Argyris and Schön 1978).

In the improvement efforts of non-routine forest regeneration services, the dialogue and interpretation of the forest owners' needs and requirements represent the starting point for the co-creation of service varieties. The teams of forestry professionals are required to search for similarities and patterns in the challenging marketing situations, which gradually enable the classification of these demanding cases into more easily interpretable schemes and skills. This gradually leads to the accumulation of competence and experience of the forestry professionals en route to creating common understanding and shared purpose for the activities with the clients. As this information is systematically collected and analysed, it may be transformed into a valuable resource of the service organisation. However, during the interventions of quality management from 2000 to 2006, the CEOs of the FOAs were not yet prepared to organise the analysis of the needs and requirements of these demanding clients.

5.1.2 Soil preparation

The soil preparation sub-process may have either its own assessment phase, in which the method of soil preparation is selected according to the information on site fertility, soil texture type, soil stoniness and wetness, or alternatively the method of soil preparation may have been chosen during the negotiations concerning the regeneration chain in the marketing sub-process. In the case of a routine process, the forestry professional has been able to recommend the method of soil preparation according to his best judgement – e.g., patching, disc trenching, or mounding. The information about the selected method of soil preparation will be relayed to a soil preparation subcontractor, who will take care of the implementation according to the algorithms agreed – i.e., guidelines and instructions. In addition to the instructions given by the service provider, different kinds of micro-sites may require an analysis of the AAA sequence at the regeneration area level. The resources of the soil preparation subcontractor (skills, machinery and equipment) may influence the output of the soil preparation sub-process.

The responsibility of the FOA and local forestry professionals is to define and negotiate the quantitative performance indicators for the soil preparation sub-process. These kinds of performance variables are, e.g., the type and quality of well-prepared planting spots as well as the target number of good-quality spots for different methods of soil preparation (Luoranen et al. 2007). It is recommended that the result of soil preparation work is evaluated through self-control measurements by the machine operator (Harstela et al. 2006, Luoranen et al. 2007). The training on proper techniques of soil preparation and self-control measurements will be a potential starting point for the quality work of this sub-process.

In mechanised direct seeding and planting, the soil preparation sub-process is combined with the regeneration work sub-process. This may be considered as a means to both increase the asset specificity and re-engineer the forest regeneration process. The adoption of new machinery and a working concept enables planting on freshly prepared planting spots of uniform quality as well as elimination of some risks related to shared responsibilities of seedling maintenance, and also provides, to some extent, economies of scale. In the case of natural regeneration, soil preparation is the final sub-process prior to awaiting the outcome of activities.

5.1.3 Choice of regeneration material

The choice of regeneration material sub-process is usually initiated in connection with the marketing of the regeneration method sub-process, where some of the information required is assessed. The choices concerning tree species, types of seedlings or seed, numbers and/or quantities are discussed together with the forest owner (Rikala 2002, Nygren 2011, Rikala 2012, Luoranen et al. 2012). Thereafter, decisions about scheduling, regeneration material storage, maintenance and delivery –i.e., supply chain management – are made (Ballou 2004). The position of this sub-process depends on the provider of the regeneration services and the quality of input information available (Lillrank 2003b). In this case, the choice of regeneration material has been inserted after the soil preparation sub-process because the area of soil preparation realised may differ from the stand area, more accurate site information may be obtained during soil preparation, and delayed bioenergy harvest may alter requirements for seedlings. Furthermore, planting in mid-summer or autumn require re-evaluation of seedling types.

The choice of regeneration material sub-process encompasses the reception, assessment, storage and maintenance of seedlings as well as management of storage rotation and logistics (Rikala 2002, Luoranen et al. 2012). Both the elimination of special causes of variation in the seedling material by more strictly closing this sub-process and diminishing the variation by common causes are relevant here. For instance, the checklists and guidelines to discover the condition of seedlings and damaging agents will be an effort to eliminate special causes of variation (Rikala 2002). On the other hand, systematic watering of seedling material at the storage terminal is an improvement effort to reduce the variation caused by common causes. In general, this sub-process may be standardised more and improved through hypothetic–deductive reasoning, experimentation and before–after comparisons. The skills and competence of the actors in different parts of the seedling supply chain require special attention, and the significance of these issues will be increasing in the future: what kind of care is required by different types of seedling lots, which are intended to be planted at different points in the growing season.

In the case of direct seeding, the choice of regeneration material sub-process includes the interdependent decisions for type, geographical origin and quantity of seed material. In the quality chain of seed material, the germination capability of the material has to be maintained by means of considering the issues related to storage, handling and distribution of seed (Nygren 2003, 2011).

5.1.4 Regeneration work

The regeneration work sub-process concentrates on the actions in the regeneration area, the purpose of which is to preserve the vitality of regeneration material and deliver it to favourable spots on the ground. In the regeneration area, these actions consist of shading and possible watering of the seedlings or proper storage of seed, and the implementation of regeneration work itself – either planting or sowing (Rikala 2002, Nygren 2011, Luoranen et al. 2012). In general, there may be challenges in the assessment and algorithm phases of regeneration work for the service providers.

Regeneration work is the most common action of self-service carried out by forest owners. At best, this variety of self-service is agreed upon within the marketing sub-process and considered when planning the operations together with the forest owner. In practice, the service provider has to design a variety of the service product, which accounts for the extra educational needs and requirements for guidance and support of these active forest owners. Depending on the case, these investments in extra activities of extension education may also serve as a means of maintaining valuable customer relations. However, in the worst case, the forest owners may have little experience and receive minimal guidance. These factors combined with poor estimation of the forest owner's own resources easily lead this process into a non-routine mode. The greatest risks lie in the maintenance and handling of the regeneration material in addition to the quality of the work – planting or manual sowing – itself.

Regeneration work that has been completely implemented by the service provider may face different kinds of challenges. The issues of timing may be determined from at least four different viewpoints, which were described in Article I. The central issue will be the selection of proper timing for the actions and the hypothetical slack between them. As the slack increases, for instance, both the utilisation of personnel and machine resources will decrease, and the requirements for extra investments due to the need for vegetation control will increase. Moreover, in the southern parts of Finland, the execution of sowing work is not recommended after mid-June (Nygren 2011). In general, the challenges involved with timing regeneration work may be approached more thoroughly through Time-Based Management (TBC) and solved by improving the assessment and algorithm phases of the concerned sub-processes.

In the regeneration work sub-process, forest workers are responsible for the storage and maintenance of regeneration material (e.g., shading and watering the seedlings or proper seed storage). This constitutes an AAA sequence of its' own. Additionally, the AAA sequence of the planting work is a crucial one. In the planting work, the key performance indicator is the number of properly planted seedlings per hectare. This indicator should be measured through self-control measurements by the forest worker. Self-control measurements have also been proposed by Harstela et al. (2006) and Luoranen et al. (2012).

The number of planted seedlings is, however, influenced by the quality of soil preparation. If a low number of good planting spots have been prepared, the risk for re-work – supplementary planting – manifests itself easily, e.g., due to biotic and abiotic damaging agents. Planting on non-scarified spots may even lower the likelihood for survival. In conclusion, appropriate selection of planting spots and proper implementation techniques contribute to the survival and future development of seedlings.

In the case of direct seeding, site fertility and soil texture type may be the most significant performance indicators to be followed in the selection of this method of regeneration. Other important performance indicators of the regeneration work sub-process may be the quantity (g per ha) and type of seed used, and the proper timing of operations (Nygren 2011). In the conditions of Southern Finland, germination of the seed sown may be inventoried separately at the end of the same summer, i.e., in late July–August. At that point, it is possible to evaluate, whether the functioning of the sowing machine and the germination capabilities of the seed have fulfilled expectations.

5.1.5 Outcome of the service process

The actual outcome of the forest regeneration services cannot be measured immediately after the operations. The highest mortality of the seedlings should have already passed, the natural supplements should have established, and neither weeds nor shrubs should have significantly influenced the growth of seedlings. In the conditions of Southern Finland, these criteria are met and the result of regeneration activities are still visible three years after planting, four years after direct seeding and five years after natural regeneration (Kalland 2002, Saksa et al. 2002, Saksa et al. 2005, Saksa and Kankaanhuhta 2007). Additionally, at this stage the need for early tending – e.g., weed control and cleaning of competing broadleaves – is assessable. On the whole, the ultimate definition of good-quality regeneration service for the end-user would be “*a good young stand*”.

In this thesis, the outcome of the forest regeneration service system was defined as a well-established young stand that has an appropriate tree species composition and the ability to utilise the production potential of the prevailing environmental conditions. The full production potential of the stand has been defined as the even, nonclustered distribution of seedlings in the stand. In other words, the target is to establish a fully stocked, healthy, well-growing young stand without delay and at reasonable cost (Räsänen 1981). It has to be emphasised that only a few of the product varieties – i.e., combinations of tree species and regeneration methods – are real options for the forest owner since the risk for failure or major losses not to mention the amount of future monitoring and work, may vary considerably between the chains of regeneration. Despite the ideal definition for the outcome of forest regeneration activities, the private forest owner may expect the service provider to offer only a certain type of forest work or regeneration material, which may deviate from the recommendations of the forestry professional and produce inconsistent results. The forest regeneration service production system resembles features of co-configuration described by Victor and Boynton (1998). However, Figures 4 and 5 show that the capabilities of the service providers to produce consistent quality vary considerably.

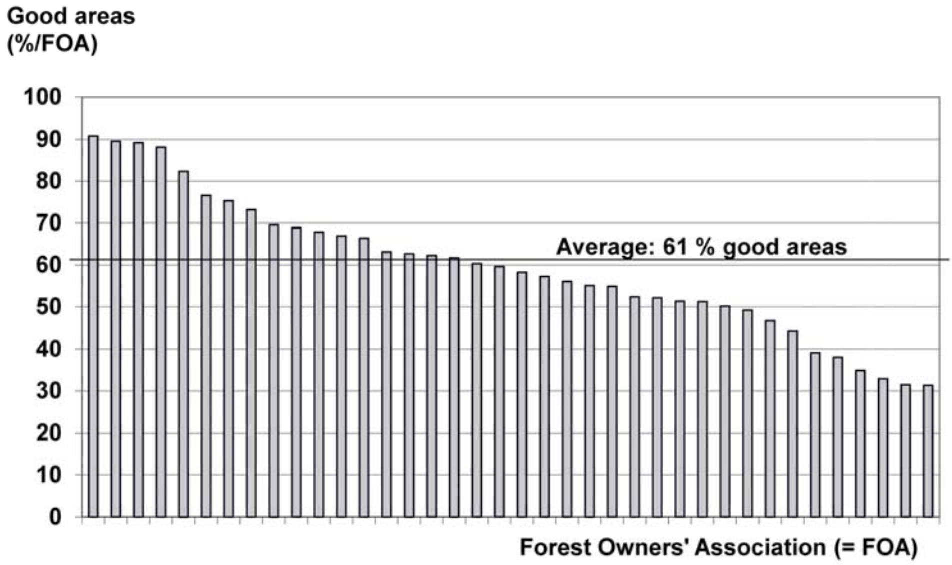

Figure 4. Proportion of good regeneration results for Norway spruce planting at the FOA level (9249 ha). The level of good regeneration result was set at 1600 crop-trees per ha. The FOAs covering less than 10 ha are not shown.

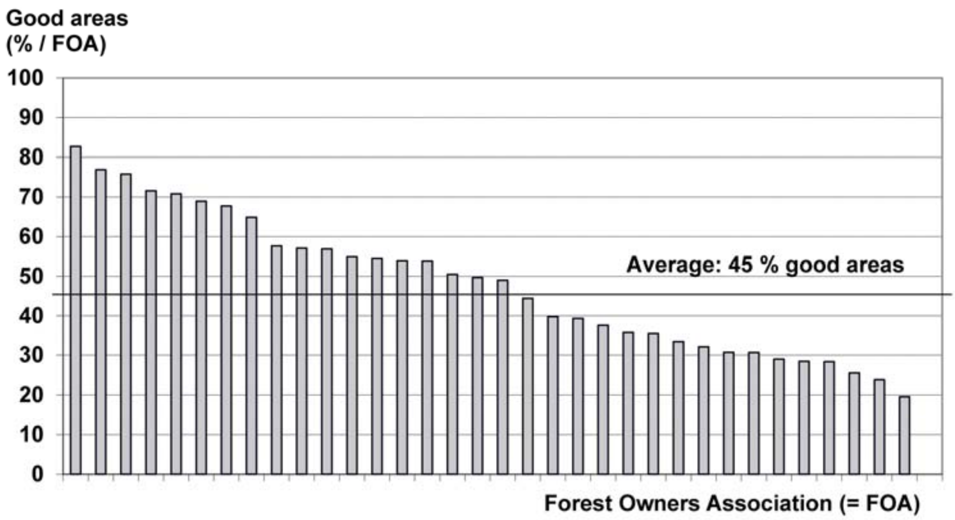

Figure 5. Proportion of good regeneration results for Scots pine direct seeding at the FOA level (5408 ha). The level of good regeneration result was set at 3000 pine seedlings per ha. The FOAs covering less than 10 ha are not shown.

The quantitative definitions for good-quality regeneration results at a certain point in time should take into account prevailing site and weather conditions, economical circumstances, and the requirements of the forest owners and stakeholders. Depending on the service offered, the performance indicator of the outcome of the activities may be defined as the mean number of seedlings at a certain point in time (e.g., Article III). Furthermore, the proportions of tree species, statistical distribution of the seedlings at sample plot level or proportion of poorly regenerated sample plots may be recommendable performance variables to be followed. In the case of offering the client only forest work service, which consists of single sub-processes – e.g., soil preparation or planting work – the number of good planting spots or properly planted seedlings should be measured by means of self-control measurements (Baker 1988).

5.2 Variation in the results of forest regeneration

5.2.1 Norway spruce planting

In the regeneration chain of Norway spruce planting, the mean number of planted seedlings was1388 per ha (SD = 378 seedlings per ha) and median 1400 seedlings per ha. In general, the average results of FOAs varied from 1200 to 1600 planted seedlings per ha (Figure 6). The variation explained by the different hierarchical levels – forestry centre, FOA, forestry professional, stand, sample plot – was modelled using linear mixed models with and without fixed effects. Forestry professional, FOA and forestry centre accounted for 5.6% of the variation in the number of planted seedlings (Table 6). The variation between the regeneration areas within the above-mentioned levels accounted for 23.2% of the variation in the number of planted seedlings. The sample plot level accounted for the greatest proportion of variation. The same significant fixed effects that were used in the GLMM of Norway spruce planting were included in the LMM. The fixed effects included reduced the total variance by two per cent.

The significant factors influencing the number of planted seedlings in the GLMM of Norway spruce planting were site fertility type, soil texture type, soil preparation method, soil stoniness and wetness (Table 7). The most dominant site fertility type was MT while the most common soil texture type was medium. Patching was used most frequently. Soil wetness and stoniness were in the minority. The most common classes of variables recorded at the sample plot level were used as reference classes. In the reference class, the number of planted seedlings was 1365 per ha ($\exp\{1.0047\}*500 = 1366$) and, e.g., stony soil reduced the number of planted spruces by 28% ($\exp\{-0.3233\} = 0.72$). Wet soil reduced the number of planted seedlings by 27%.

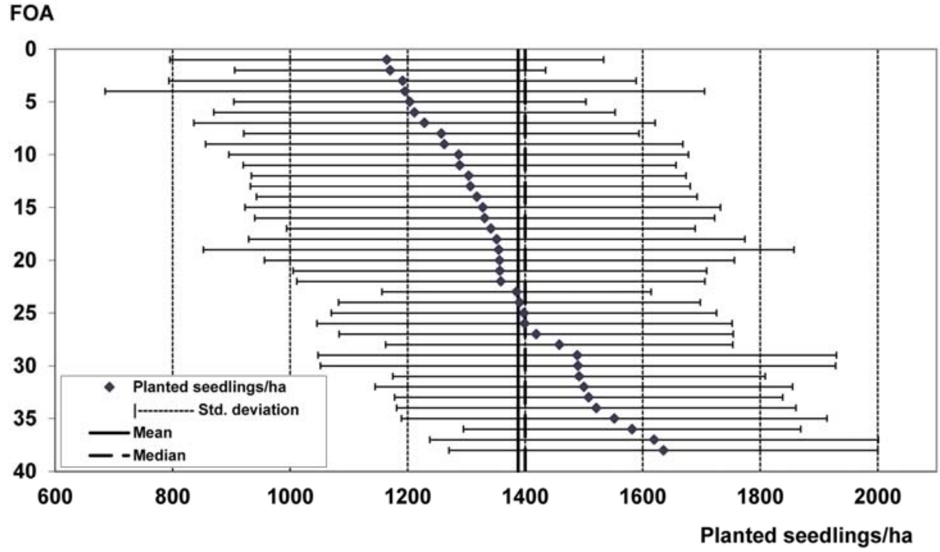

Figure 6. Variation of Norway spruce planting results between Forest Owners' Associations (=FOAs). Dots indicate area-weighted averages for planted seedlings in the regeneration areas in the FOAs. The bars indicate standard deviations on both sides of the dots. The solid line indicates the general mean and broken line the general median. The FOAs with < 10 ha regeneration area were omitted from the figure.

Table 6. Norway spruce planting, with variance explained at different hierarchical levels: ICC. The fixed effects or predictors are the same as in Table 7.

Level	Variance estimate	Std. error	Proportion, %	ICC (VPC)
Linear mixed model without fixed effects				
Forestry centre	0.0078	0.0102	0.3	0.3
FOA	0.0336	0.0145	1.5	1.8
Professional	0.0885	0.0124	3.8	5.6
Reg. area	0.4042	0.0108	17.6	23.2
Residual	1.7659	0.0092	76.8	100.0
Linear mixed model with fixed effects				
Forestry centre	0.0115	0.0116	0.5	0.5
FOA	0.0262	0.0125	1.2	1.7
Professional	0.0873	0.0122	3.9	5.6
Reg. area	0.3957	0.0106	17.6	23.2
Residual	1.7278	0.0091	76.8	100.0

Site types that were more fertile than MT reduced the number of seedlings by 3%. In the case of less fertile site types (i.e., VT, CT, or ClT), the reduction in the number of planted seedlings was 2%. Fine-textured mineral soil reduced the number of seedlings planted by four per cent compared with medium coarse mineral soil. The peat soil type reduced the number of planted seedlings by 10%. In addition, there was no difference in the results between medium and coarse mineral soils. In the case of no soil preparation in the area of the sample plot, the number of seedlings was reduced by 20%. Mounding produced the best results with a 9% increase in the number of planted seedlings compared to patching. As patching was compared with disc trenching, there was practically no effect. The effect of other miscellaneous soil preparation methods was not statistically significant.

In the GLMM for Norway spruce planting, the residual variation at the plot level was modelled using the dispersion parameter var(e_{mlkji}). This parameter is interpreted as the difference in the spatial distribution of trees from the Poisson distribution. The dispersion parameter value was 0.6635, which indicates underdispersion due to the even spatial distribution of the seedlings compared with the Poisson distribution.

Table 7. Parameter estimates, variance components and approximate standard errors for the number of planted spruces. The reference class applied was no stones, no wetness, MT site type, patching and medium coarse soil type. The proportion (%) shows the effect of parameter compared with the reference class.

Predictor	Number of trees per 20 m^2			Proportion, %	
	Planted spruces	Std. error	EXP(estimate)	(+ / -)	
Intercept	1.00470	0.02248	2.73		***
Stony soil	-0.32330	0.01338	0.72	-28	***
Wet soil	-0.31190	0.01361	0.73	-27	***
Site type					
OMaT or OMT	-0.03534	0.00635	0.97	-3	***
VT or CT or Clt	-0.02309	0.01156	0.98	-2	*
Soil preparation					
No preparation	-0.22390	0.01809	0.80	-20	***
Disc trenching	0.00611	0.01007	1.01	1	ns
Mounding	0.08474	0.00944	1.09	9	***
Other	0.06397	0.05339	1.07	7	ns
Soil texture					
Coarse mineral	-0.00943	0.01277	0.99	-1	ns
Fine mineral	-0.04093	0.00594	0.96	-4	***
Peat	-0.10510	0.01070	0.90	-10	***
var(u_m)	0.00149	0.00163			
var(u_{ml})	0.00373	0.00189			
var(u_{mlk})	0.01468	0.00202			
var(u_{mlkj})	0.06127	0.00162			
var(e_{mlkji})	0.66350	0.00349			

* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. “ns” = non significant at 0.1 level.

5.2.2 Scots pine direct seeding

In the regeneration chain of Scots pine direct seeding, the mean number of Scots pine seedlings was 3075 per ha (SD = 1644 seedlings per ha) and median 2813 seedlings per ha. The average results of FOAs varied from 2000 to 5000 pine seedlings per ha (Figure 7). The variation explained by the different hierarchical levels was modelled using LMMs, with and without fixed effects, employing a hierarchical structure similar to that used in Norway spruce planting (Table 8). The forestry centre level accounted for 2.2% of the variation in the number of Scots pine seedlings. Forestry centre and FOA accounted for 6.9% of the variation. The forestry professional level together with the upper levels accounted for 13.4% of the variation. The regeneration area level together with the upper levels accounted for 41.1% of the variation. The sample plot level accounted for the greatest proportion of the variation in the number of pine seedlings. When the significant fixed effects, which are more thoroughly described in the context of GLMM modelling, were included in the LMM for Scots pine direct seeding, the total variance was reduced by 9.3%.

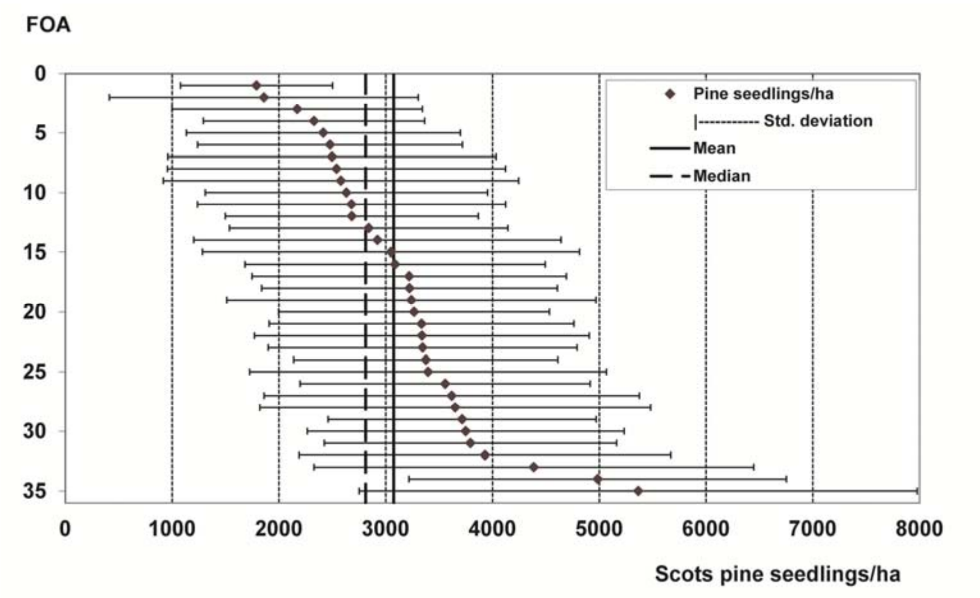

Figure 7. Variation of Scots pine direct seeding results between Forest Owner's Associations (=FOAs). Dots indicate the area-weighted averages of pine seedlings in the regeneration areas in the FOAs. The bars indicate standard deviations on both sides of the dots. The solid line indicates the general mean and the broken line the general median. The FOAs with < 10 ha regeneration area were omitted from the figure.

Table 8. Scots pine direct seeding; variance explained at different hierarchical levels: ICC. The fixed effects or predictors are the same as in Table 9.

Level	Variance estimate	Std. error	Proportion, %	ICC (VPC)
Linear mixed model without fixed effects				
Forestry centre	0.6047	0.5576	2.2	2.2
FOA	1.2942	0.5021	4.7	6.9
Professional	1.8048	0.3265	6.5	13.4
Reg. area	7.6765	0.2597	27.7	41.1
Residual	16.3353	0.1200	58.9	100.0
Linear mixed model with fixed effects				
Forestry centre	0.5584	0.4992	2.2	2.2
FOA	1.0768	0.4217	4.3	6.5
Professional	1.5524	0.2798	6.2	12.7
Reg. area	6.3999	0.2204	25.5	38.1
Residual	15.5506	0.1146	61.9	100.0

In the GLMM for Scots pine direct seeding, the significant factors influencing the number of pine seedlings were site fertility type, soil texture type, methods of soil preparation and sowing, as well as stoniness and wetness (Table 9). In this regeneration chain, the dominant site type was MT while the most common soil texture type was medium coarse mineral soil. The regeneration areas were most frequently disc trenched and sown mechanically. The most common characteristics of the regeneration sample plots were used as a reference class in modelling. In the reference class, the total number of sown and naturally regenerated Scots pine seedlings was 2531 per ha.

Site types that were more fertile than MT reduced the number of pine seedlings by 39%. On VT sites, the number of pine seedlings increased by 33% compared with MT. The combined fertility classes CT and ClT increased the number of seedlings by 43%. Coarse mineral soil increased the number of seedlings by 5% compared with medium mineral soil. On fine mineral and peat soils, the number of seedlings was reduced by 15%. Stony soil reduced the number of seedlings by 32%. Wet soil, for its part, reduced the number of seedlings by 31%.

Compared to the most commonly used soil preparation method – disc trenching – on non-prepared sample plots, the number of pine seedlings was reduced by 44%. Mounding, in contrast, increased the number of seedlings by 9%. Almost 90% of the mounded plots were sown manually, and the rest of the plots were sown by a machine, which was attached to an excavator. Patching and other soil preparation methods did not lead to any statistically significant differences with respect to disc trenching. Compared to the sample plots sown by machine, manual sowing reduced the number of seedlings by 14%.

In the GLMM for Scots pine direct seeding, the normal probability plots of the predicted random effects supported the approximate normality of the random effects. There was no evidence of non-constant residual variation in the residual plots. At the sample plot level, the residual variation was modelled using the dispersion parameter var(e_{mlkji}) that was interpreted as the difference in the spatial distribution of seedlings from the Poisson distribution. The value of the dispersion parameter was 2.5776, which indicates overdispersion due to the clustered spatial distribution of the seedlings compared to the Poisson distribution.

Table 9. Parameter estimates, variance components and approximate standard errors for the total number of regenerated pines. The reference class applied was no stones, no wetness, MT site type, disc trenching and medium coarse soil type. The proportion (%) shows the effect of parameter compared to reference class.

Predictor	Number of trees per 20 m^2			Proportion, %	
	Pine seedlings	Std. error	EXP(estimate)	(+ / -)	
Intercept	1.6219	0.0620	5.06		***
Stony soil	-0.3836	0.0195	0.68	-32	***
Wet soil	-0.3724	0.0228	0.69	-31	***
Site type					
OMaT or OMT	-0.4931	0.0361	0.61	-39	***
VT	0.2882	0.0110	1.33	33	***
CT or ClT	0.3550	0.0232	1.43	43	***
Soil preparation					
No preparation	-0.5863	0.0620	0.56	-44	***
Patching	0.0170	0.0314	1.02	2	ns
Mounding	0.0826	0.0404	1.09	9	*
Other	-0.0287	0.1466	0.97	-3	ns
Soil texture					
Coarse mineral	0.0445	0.0138	1.05	5	**
Fine mineral	-0.1680	0.0147	0.85	-15	***
Peat	-0.1684	0.0190	0.85	-15	***
Sowing method					
Manual	-0.1555	0.0282	0.86	-14	***
var(u_m)	0.0127	0.0128			
var(u_{ml})	0.0340	0.0130			
var(u_{mlk})	0.0443	0.0082			
var(u_{mlkj})	0.1866	0.0066			
var(e_{mlkji})	2.5776	0.0190			

* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. “ns” = non significant at 0.1 level.

5.3 Cost–quality relationship of forest regeneration activities

5.3.1 Norway spruce planting

The cost–quality relationship was studied first by comparing the regeneration costs with the number of planted seedlings and crop-trees. At the stand level, a minor correlation (r = 0.10, p = 0.05) was found between the regeneration costs and number of crop-trees. The correlation between the regeneration costs and seedlings planted was a little greater (r = 0.15, p = 0.01). On the other hand, the correlation between the cost of regeneration and number of supplementary crop-trees was insignificant (r = -0.04, p = 0.47). At the municipal level, neither the mean number of crop-trees (r = 0.14, p = 0.53) nor the number of seedlings planted (r = 0.21, p = 0.32) correlated with regeneration costs. Next, the cost–

quality relationship was studied via comparison of the regeneration costs with the proportion of well-regenerated regeneration areas. Figure 8 indicates that the cost of regeneration and proportion of well-regenerated stands did not correlate at the municipal level ($r = 0.09$, $p = 0.66$).

Lastly, the local site characteristics, which were hypothesised to influence the cost–quality relationship, were incorporated into the multilevel model. The most common classes of these variables recorded were used as a reference class. The dominant site fertility type was MT and the corresponding soil texture type was medium coarse mineral soil. Soil stoniness and wetness were not dominant site attributes. The analysis results obtained were unexpected. The hypothesised site features did not significantly influence the result of regeneration activities, i.e., number of crop-trees. Thus, these variables were omitted from the final model.

The cost of the Norway spruce planting service was only weakly related to the quality of the outcome of these activities (Table 10). The estimated mean for crop-trees was 1522 per ha. The relationship between the investment of 100€ and the number of crop-trees manifested an increase of 33 seedlings per ha. The outcome of Norway spruce planting services differed significantly between the municipalities although the site characteristics were taken into account. Altogether, the variation in the regeneration results between municipalities accounted for 18% of the total variance of the crop-trees per ha.

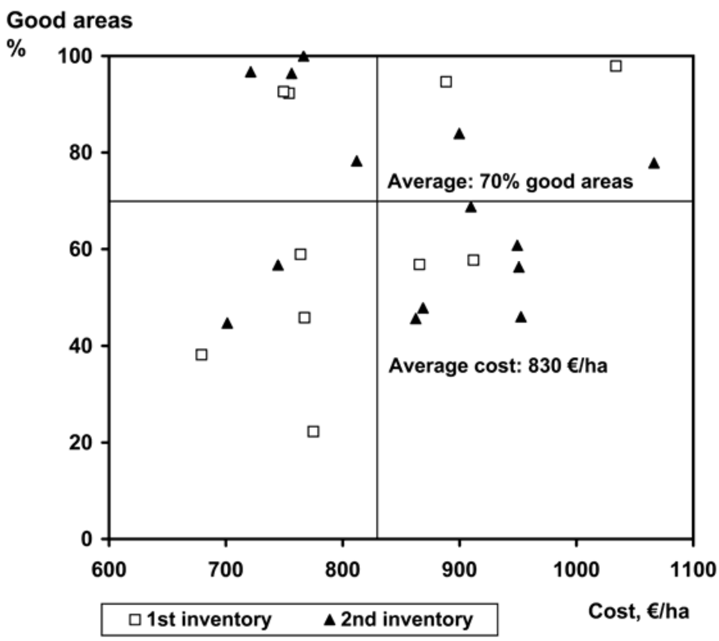

Figure 8. The relationship between the cost of Norway spruce planting and proportion of well-regenerated regeneration areas at the municipal level (847 ha). Area-weighted means were used in the calculations.

Table 10. Parameter estimates, standard errors, χ^2 test values and variance components of the equations for total number of crop-trees in Norway spruce planting and number of regenerated pines in Scots pine direct seeding.

Predictor	Crop-trees of N. s. planting/ha			Scots pine seedlings/ha		
	Estimate	SE	χ^2 -value	Estimate	SE	χ^2 -value
Intercept	1521.92	123.84	151.03***	1707.46	479.53	12.68***
Cost (€/ha)	0.33	0.14	5.88*	6.54	1.48	19.58***
	–	–	–			
Site type	–	–	–	Joint test		73.05***
MT or OMT	–	–	–	-815.16	137.51	35.14***
CT or ClT	–	–	–	1212.38	244.79	24.53***
No dominant	–	–	–	-536.45	611.04	0.77 ns
Soil texture	–	–	–	Joint test		14.92**
Coarse	–	–	–	436.12	198.34	4.84*
Fine	–	–	–	-681.96	231.83	8.65**
Peat	–	–	–	-88.97	356.86	0.06 ns
No dominant	–	–	–	-184.76	291.83	0.40 ns
Stony soil	–	–	–	-870.55	259.76	11.23***
Random Part						
SD(u_j)	176.67	109.36		709.58	427.01	
SD(e_{ji})	383.01	102.80		1441.70	351.13	

Note: Cost (€/ha) denotes the regeneration cost of the above-mentioned regeneration chain. “N. s.” denotes to “Norway spruce”. “Joint test” denotes a joint test of the dummy variables, which were created for every value of a class variable.
* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. “ns” = non-significant at 0.1 level.

5.3.2 Selection of methods and implementation of Norway spruce planting

The selection and implementation of regeneration methods that could influence the cost–quality relationship of Norway spruce planting were explored through multivariate multilevel model (Table 11). The dependent variables for the sub-models of Norway spruce planting were: 1) the number of planted seedlings; 2) the number of naturally regenerated supplementary seedlings; and 3) the cost of regeneration activities. The most common classes of variables recorded were used as the reference classes. The dominant site type was MT and the corresponding soil texture type was medium coarse mineral soil. Patching was the most frequently used soil preparation method and the seedlings delivered were 1.5 years or older in almost 70% of the cases.

Table 11. Norway spruce planting. Parameter estimates and variance components of the equations for number of planted spruces, naturally regenerated supplementary seedlings, and cost of regeneration. The most common values of the class variables were used as a reference class.

Predictor	Planted N. spruce seedlings/ha			Supplementary crop-trees/ha			Regeneration cost, €/ha		
	Estimate	SE	χ^2 -value	Estimate	SE	χ^2 -value	Estimate	SE	χ^2 -value
Intercept	1020.21	113.17	81.27***	336.18	33.74	99.3 ***	238.77	29.82	64.12***
Site type	Joint test		2.84 ns	Joint test		7.52 ~	Joint test		3.12 ns
OMT	2.53	40.49	0.004 ns	-81.43	30.53	7.11 **	-10.637	9.23	1.33 ns
VT	129.55	113.86	1.30 ns	-61.51	86.87	0.50 ns	-30.96	25.81	1.44 ns
No dominant	283.91	226.07	1.58 ns	43.25	173.07	0.06 ns	35.69	51.36	0.48 ns
Soil texture	Joint test		3.57 ns	Joint test		3.86 ns	Joint test		6.80 ns
Coarse mineral	-121.46	98.48	1.52 ns	10.20	74.92	0.02 ns	-15.05	22.49	0.45 ns
Fine mineral	-64.76	45.57	2.02 ns	-13.28	34.74	0.15 ns	-11.35	10.40	1.19 ns
Peat	-80.35	93.31	0.74 ns	125.54	71.30	3.10 ~	28.87	21.20	1.86 ns
No dominant	-22.04	72.10	0.09 ns	28.85	54.66	0.28 ns	-26.32	16.56	2.53 ns
Soil preparation	Joint test		0.48 ns	Joint test		4.68 ns	Joint test		72.03***
No preparation	90.97	203.91	0.20 ns	-271.80	150.23	3.27 ~	-97.79	46.70	4.39 *
Disc trench.	-5.14	46.53	0.01 ns	7.32	34.07	0.05 ns	-69.60	10.95	40.41***
Mounding	23.69	53.33	0.20 ns	-40.25	39.37	1.05 ns	32.66	12.39	6.95**
Delivered seedlings	0.29	0.06	22.11 ***	–	–		0.38	0.01	739.49***
Seedling type	Joint test		2.56 ns				Joint test		160.20***
Bare root	65.36	58.33	1.26 ns	–	–		125.40	13.51	86.10***
One-year-old	-45.16	47.92	0.89 ns	–	–		-76.78	11.21	46.94***
Stand area, ha	–	–		–	–		-4.54	2.12	4.35*
Random part: SD(u_j)	178.22	105.61		119.58	72.64		73.27	40.70	
Random part:SD(e_{ji})	309.58	83.10		237.44	63.73		69.80	18.74	

Note: “Joint test” denotes a joint test of the dummy variables created for every value of a class variable.

~ significant at 0.10, * significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. ‘ns’ = non-significant at 0.1 level.

In the case of the sub-model for planted seedlings, the number of seedlings planted was 1020 per ha for the reference class. One seedling delivered to the regeneration area increased the number of planted seedlings inventoried by 0.29 per ha. For example, in the case of the average number of seedlings delivered (1717 seedlings per ha), the predicted number of planted seedlings would be 1020 + (0.29*1717) ≈ 1518 seedlings per ha. In this sub-model, it was unexpected to find that site type, soil texture type, and soil preparation method did not significantly influence the number of planted seedlings. The combined level of municipality and year accounted for 25% of the total variation in the number of seedlings planted.

In the sub-model for the naturally regenerated supplementary seedlings of Norway spruce planting, the number of those seedlings was 336 per ha in the reference class. On OMT sites, the naturally regenerated supplementary seedlings were reduced by 81 per ha compared with the MT sites. Furthermore, the peat soils (β = 126) and sites with less than 50% of soil preparation coverage (β = -272) were nearly significant. Soil stoniness and wetness were not significant predictors in these sub-models. The combined level of municipality and year accounted for 20% of the total variation in the naturally regenerated supplementary crop-trees.

For the cost of regeneration sub-model, the hypothesised influence of site fertility and soil texture type on regeneration cost did not emerge as significant. There was no influence of, e.g., more difficult site and soil conditions on the selection of soil preparation method and number and type of seedlings, which, in turn, would have influenced the costs. The influence of the soil preparation method and the number and type of seedlings on the cost of regeneration was logical and statistically significant. In addition, as expected, a one-hectare increase in the area of a regeneration area decreased the unit costs of regeneration activities by 4.5€ per ha. The combined level of municipality and year accounted for 52% of the total variation in regeneration cost.

The covariance structure of the multivariate multilevel model for Norway spruce planting is shown in Table 12. These covariances of the random effects were not statistically significant at either the stand level or the combined municipality and year level. Table 13 shows the insignificant correlations that were calculated from the covariance matrix.

Table 12. Covariances among the combined municipality and year random effect (upper triangle) and regeneration area random errors (lower triangle) of the regeneration result and cost models. Standard errors and significances are presented in brackets.

Response variable	Planted seedlings/ha	Suppl. crop-trees/ha	Regen. cost, €/ha
Planted seedlings/ha	–	-8772.03 (5744.02 ns)	473.44 (3042.81 ns)
Suppl. crop-trees/ha	-5188.56 (3754.03 ns)	–	2333.24 (2144.90 ns)
Regen. cost/ha	-686.63 (1101.79 ns)	-802.77 (845.56 ns)	–

Note: “Suppl. crop-trees” = supplementary crop-trees, “Regen. Cost” = cost of forest regeneration, “ns” = non-significant at 0.1 level.

Table 13. Correlations among the combined municipality and year random effects (upper triangle) and regeneration area random errors (lower triangle) of the regeneration result and cost models.

Response variable	Planted seedlings/ha	Suppl. crop-trees/ha	Regen. cost, €/ha
Planted seedlings/ha	1	-0.412	0.036
Suppl. crop-trees/ha	-0.071	1	0.267
Regen. cost/ha	-0.032	-0.048	1

Note: “Suppl. crop-trees” = supplementary crop-trees, “Regen. cost” = cost of forest regeneration.

5.3.3 Scots pine direct seeding

The cost–quality relationship of Scots pine direct seeding was studied first through comparison of the regeneration costs with the number of Scots pine seedlings inventoried. At the stand level, the regeneration costs and number of pine seedlings correlated to a small extent (r = 0.26, p = 0.01). At the municipal level, the regeneration costs and mean number of pine seedlings did not correlate (r = 0.32, p = 0.12). Next, the cost–quality relationship was studied in a comparison of the regeneration costs with the proportion of well-regenerated areas. Figure 9 shows that the inputs for regeneration activities and the proportion of well-regenerated stands did not correlate at the municipal level (r = 0.24, p = 0.24). In addition, it was observed that actors in certain municipalities had selected, for instance, more costly methods of soil preparation and sowing, which were rarely applied in other municipalities. It was possible to consider these cases in the multivariate multilevel models.

Finally, the values of hypothesised factors that could affect the cost–quality relationship of Scot pine direct seeding were estimated for the multilevel model (Table 10). The dominant classes of site features were used as a reference class. The most common site fertility and soil texture types were VT and medium coarse mineral soil, respectively. Stoniness and wetness were not dominating. In these site conditions, the estimated mean for the number of pine seedlings was 1707 per ha. The cost of regeneration and quality correlated significantly. The relationship between the investment of 100€ and the number of pine seedlings manifested an increase of 654 seedlings per ha.

The selection of Scots pine direct seeding in fitting site conditions proved to be a noteworthy issue. As expected, the outcome of forest regeneration activities was influenced by site fertility, soil texture type as well as soil stoniness. The effect of average investment on the outcome of this service variety was significantly better on CT or ClT sites (β = 1212 seedlings per ha), and on coarse mineral soil (β = 436 seedlings per ha). In contrast, the impact of this investment was substantially less on OMT or MT sites (β = -815 seedlings per ha), and on fine mineral soil (β = -682 seedlings per ha). Furthermore, stony soil reduced the number of pine seedlings by 871 per ha. The influence of soil wetness on regeneration results was not statistically significant in the model, and thus discarded. The outcome of Scots pine direct seeding activities differed significantly between the municipalities although site characteristics were taken into account. The municipal level explained 20% of the total variation in the number of pine seedlings.

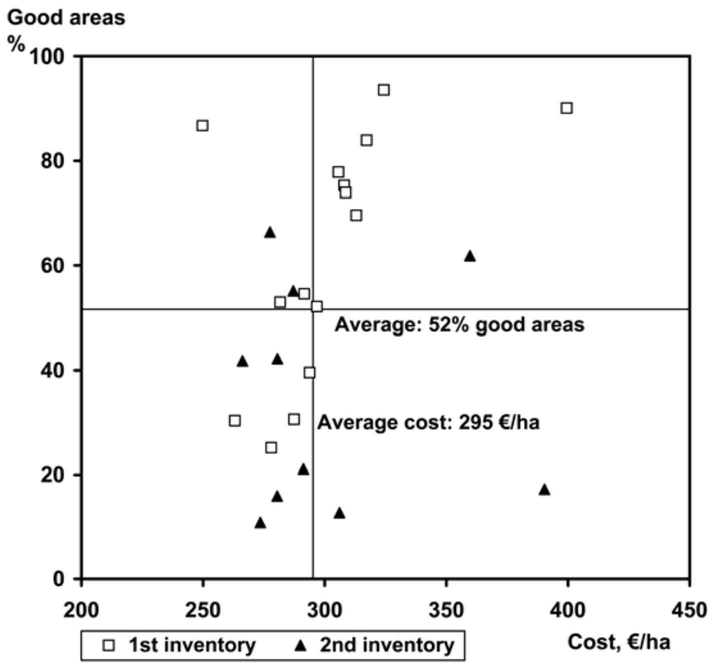

Figure 9. The relationship between the cost of Scots pine direct seeding and well-regenerated regeneration areas at the municipal level (1362 ha). Area-weighted means were used in the calculations.

5.3.4 Selection of methods and implementation of Scots pine direct seeding

The selection and implementation of regeneration methods that could influence the cost–quality relationship of Scots pine direct seeding were explored through multivariate multilevel model (Table 14). The dependent variable for the first sub-model was the total number of pine seedlings including both sown and naturally regenerated, whereas that for the second sub-model was the cost of regeneration activities. The most common classes of site variables were used as the reference classes. The dominant site fertility type was VT, while the most common soil texture type was medium coarse mineral soil. Disc trenching was the prevailing soil preparation method, and mechanised sowing was predominant.

In the sub-model for Scots pine seedlings, the estimated mean for the number of those seedlings was 2586 per ha. Site fertility, soil texture type, soil stoniness, and quantity of seed sown all influenced the result of regeneration operations as expected. One gram of seeds increased the number of pine seedlings by 3.6 seedlings per ha. For example, in the case of average quantity of seed (349.5 g per ha), the number of pine seedlings predicted would be 2586 + (3.63*349.5) ≈ 3855 seedlings per ha. Furthermore, as the information for seed sown was available, the method of sowing (i.e., mechanised or manual) proved to be a statistically insignificant predictor.

Table 14. Scots pine direct seeding. Parameter estimates and variance components of the equations for the total number of regenerated pines and cost of regeneration. The most common values for the class variables were used as a reference class.

Predictor	Scots pine seedlings/ha			Regeneration cost, €/ha		
	Estimate	SE	χ^2 -value	Estimate	SE	χ^2 -value
Intercept	2586.07	385.82	44.93***	200.07	9.99	400.96***
Site type	Joint test		71.27 ***	Joint test		1.92 ns
MT or OMT	-779.96	136.41	32.69 ***	4.25	3.24	1.72 ns
CT or ClT	1226.69	243.58	25.36 ***	-0.77	5.72	0.02 ns
No dominant	-546.96	608.64	0.81 ns	-1.10	14.29	0.01 ns
Soil texture	Joint test		13.36 ***	Joint test		2.39 ns
Coarse	406.32	196.50	4.28 *	-3.41	4.66	0.54 ns
Fine	-638.22	230.50	7.67 **	-3.60	5.42	0.44 ns
Peat	45.18	355.02	0.02 ns	9.13	8.34	1.20 ns
No dominant	-213.04	289.69	0.54 ns	-1.07	6.86	0.02 ns
Stony soil	-925.54	255.46	13.13 ***	0.32	6.13	0.01 ns
Seed (g/ha)	3.63	1.02	12.75 ***	0.31	0.03	157.56***
Soil preparation						
Other	-270.98	251.79	1.16 ns	60.89	6.06	100.91***
Stand area, ha	–	–	–	-2.44	0.73	11.32***
Random part						
SD(u_j)	763.99	452.02		23.52	13.40	
SD(e_{ji})	1436.89	349.88		33.66	8.20	

Note: “Other” in soil preparation denotes, e.g., patching or mounding. “Joint test” denotes a joint test of the dummy variables, which were created for every value of a class variable.
* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level. “ns” = non-significant at 0.1 level.

On MT or more fertile sites, there were 780 fewer pine seedlings per ha than on VT. In contrast, dry CT or barren ClT site status increased the number of pine seedlings by 1227 per ha. Coarse mineral soil increased the number of pine seedlings by 406 per ha compared with medium mineral soil. On the other hand, fine mineral soil decreased the number of pine seedlings by 638 per ha. Soil wetness was not statistically significant, and stony soil reduced the number of pine seedlings by 926 per ha. Neither sowing nor soil preparation method was a significant predictor in this sub-model. However, method of soil preparation was retained in the model since it was required for the description of the cost structure in the sub-model for regeneration costs. The combined level of municipality and year accounted for 22% of the total variation in the sub-model for the number of pine seedlings.

For the sub-model addressing the cost of regeneration activities, the hypothesised influence of site conditions on the cost of regeneration proved to be statistically insignificant. The cost of regeneration did not increase as local site conditions became more challenging. The influence of both the method of soil preparation and quantity of seed was consistent in addition to being statistically significant. Furthermore, as expected, an increase in stand area of one hectare reduced the cost of regeneration activities by 2.4€ per ha. The combined level of municipality and year accounted for 33% of the variation in regeneration cost.

Finally, the covariance structure of the multivariate multilevel model for direct seeding of Scots pine was studied. The covariance between the number of pine seedlings and cost of regeneration was 13530.86 (SE = 5144.51, significant at 0.01 level) at the municipal level. At the stand level, the covariance was 6939.47 (SE = 2048.90, significant at 0.001). Because the covariances were statistically significant, the correlations that were calculated via the covariance matrix were also significant. The correlation between the cost of regeneration and the number of pine seedlings was 0.75 at the combined municipality and year level. At the stand level, the correlation was 0.14.

5.3.5 Fit of the models for cost–quality relationship

The fit of the multilevel models for Norway spruce planting and Scots pine direct seeding was explored by comparing variances of the models with and without significant fixed effects at both levels of the hierarchy. In the case of Norway spruce planting, the cost of regeneration activities explained 2.5% of the variation in the number of crop-trees at the municipal level. Respectively, these costs accounted for 1.1% of the variance at the stand level. In the case of Scots pine direct seeding, the fixed effects explained 41.6% of the variation in the total number of pine seedlings at the municipal level. At the stand level, the fixed effects accounted for 16.5% of the variance of pine seedlings.

5.4 Effects of quality management interventions

In the mail surveys conducted after the quality management interventions, the participant forestry professionals were requested to rank the root causes for the inventory results according to the feedback that they had obtained. Table 15 displays the most common reasons for the poor results of regeneration activities that were ranked by the forestry professionals. The three main reasons given were related to the type of soil preparation prior to planting Norway spruce, artificial regeneration of Scots pine on excessively fertile sites, and insufficiently low planting densities.

The most important improvement objectives were investigated in an open enquiry directed towards the forestry professionals. Table 16 shows the proportions of determined objectives after the quality management interventions. Changes in the methods of soil preparation accounted for the greatest proportion (29%) of the objectives set. The second most common objective set was the selection of a regeneration chain appropriate for the site conditions (21%). Other notable objectives concerned the planting density and quality of regeneration work (15%) as well as the selection of proper seedling material (10%).

Table 15. Forestry professionals' rankings (1‑9) of the reasons for their poor inventory results (the 2007 survey). The proportions of ranking between 1 and 3 were added together. (n=126).

Reasons for the inventory results obtained	Proportions (ranks 1-3), %	Mode of rank	Responses (n)
Too light or wrong type of soil preparation method for Norway spruce	67	1	106
Direct seeding of Scots pine on too fertile site type	52	1	98
Too low planting densities (seedlings per ha)	41	2	93
Planting of Scots pine on too fertile site type	35	3	89
Too small seedling type of Norway spruce	22	4	85
Too slow execution of regeneration chain after cutting	18	5	79
Too small amount of seed in Scots pine direct seeding (g per ha)	13	7	71
Too late execution of direct seeding in the middle of summer	12	8	75
Other reason	6	3	13

Table 16. The proportions of objectives determined after the feedback meetings (the 2007 survey). The proportions of the three most important objectives were added together.

Objective	Proportion, %
Change / selection of soil preparation method (usually further mounding methods)	29
Selection of regeneration chain according to site conditions	21
Planting density / quality of planting work	15
Selection of seedling material (increase in larger seedlings)	10
Density of planting spots and quality of soil preparation	7
Other objective (pre-commercial thinnings, general quality etc.)	5
Control measurements / quality work / guarantees	4
Change in sowing method	3
Intention to produce faster regeneration chains from harvest to regeneration work	2
Marketing of proper regeneration chain, extension education and training	1
Proper care and delivery of seedlings	1
Greater quantity of sown seed	1
Earlier timing of sowing work	1
Total	100

The effort of standardisation of forest regeneration activities into routine processes was observable. Better predictability of the mounding methods in the planting of Norway spruce was detected, and the resourcing was under transition into the consolidation of this variety of Norway spruce planting service. In the participant FOAs, the number of soil preparation contractors using excavators had increased by 16% more compared with the control FOAs (Table 17). Correspondingly, the excavator contractors had acquired 23% more soil preparation equipment in the participant FOAs. According to the responses of participant forestry professionals, the soil preparation equipment acquired consisted of patch mounding equipment (64%), unspecified buckets (16%), and excavators themselves (16%). Patch mounding equipment was defined here as a blade that turns the humus layer upside down forming a flat mound with a double humus layer. The rest of the soil preparation equipment included, for instance, buckets for inverting. Inverting was defined as piling a mineral soil heap on the mounding pit consequently establishing a single humus layer inside the heap. Among the non-participant FOAs, patch mounding equipment accounted for 43% of the responses, unspecified buckets for 26%, and excavators themselves for 24%.

Table 17. Changes in the available resources for the forest regeneration service process.

Information intended to be measured	Survey year	Partici-pation	Proportion, % Yes	ICS	No	No. of responses	χ^2 -va-lue
Increase in the number of soil preparation contractors using an excavator	2006	Part.	45	(-)	55	125	0.20
	2006	Non-p.	48	(-)	52	60	
	2007	Part.	59	(-)	41	122	4.91*
	2007	Non-p.	43	(-)	57	79	
Acquisition of new soil preparation equipment	2006	Part.	48	(-)	52	123	10.05**
	2006	Non-p.	73	(-)	27	59	
	2007	Part.	80	(-)	20	118	11.74***
	2007	Non-p.	57	(-)	43	79	
Soil preparation machine operators have participated in education sessions	2006	Part.	89	3	8	126	4.10
	2006	Non-p.	80	10	10	60	
	2007	Part.	92	6	2	121	6.96*
	2007	Non-p.	85	4	11	79	
Planting workers have participated in education sessions	2006	Part.	58	3	39	126	0.001
	2006	Non-p.	58	4	38	60	
	2007	Part.	80	6	14	123	8.23*
	2007	Non-p.	66	4	30	79	
Self-control measurements of soil preparation and planting density	2006	Part.	37	3	60	126	1.42
	2006	Non-p.	28	5	67	60	
	2007	Part.	54	7	39	123	9.35**
	2007	Non-p.	44	0	56	78	
Self-control measurements of germination of Scots pine seed at the end of the sowing summer	2006	Part.	18	(-)	82	125	1.25
	2006	Non-p.	12	(-)	88	59	
	2007	Part.	16	(-)	84	121	1.20
	2007	Non-p.	10	(-)	90	78	

Note: “Participation” = Participation in forest regeneration quality management. “Part.” = Participant, “Non-p.” = Non-participant. “ICS” = I cannot say.
(-) = This alternative was not available for the respondents. * significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level.

The skills of the soil preparation and planting workers to assess the site conditions, execute operations, and evaluate the quality of results were acknowledged to some extent. In the participant FOAs, the machine operators took part in soil preparation education 7% more than in non-participant FOAs. Planting workers of the participant FOAs attended seedling material tending and planting education 14% more frequently than those of non-participant FOAs. In addition, the self-control measurements of soil preparation and planting density were adopted 10% more frequently in the participant FOAs. Finally, the participation of the planting workers in education was compared with the adoption of self-control measurements of planting density. In the case of participant FOAs, the responses confirmed that there had been training concerned with planting work and that self-control measurements of planting density had been adopted 17% more frequently (Table 18).

The start of the forest regeneration service process – selection of the regeneration chain – revealed few improvements. According to the 2007 survey, there was no significant difference in the number of visits made to inspect site and soil information between participant and non-participant forestry professionals (Table 19). In addition, the rationale behind the negotiations for selecting an appropriate regeneration chain for a forest owner was investigated. New ways to explain the regeneration chains were noted 14% more frequently amongst the participant forestry professionals compared with the non-participants. In an open question about the contents of new argumentation, feedback from the inventories combined with personal experience was named by 29% (n = 35) of the participant forestry professionals. Since the non-participant forestry professionals had no opportunity to access the feedback from the inventories, information gathered from quality management research and personal experiences were used as the classification criteria. This argumentation was used by 13% (n = 10) of the non-participant forestry professional respondents.

In the soil preparation sub-process of Norway spruce planting, the most common methods selected were mounding and patching. In the 2006 survey, a total of 82% of the participant forestry professionals used these methods, while the figure for the non-participant forestry professionals was 63%. In the 2007 survey, the proportion of mounding and patching was ca. 90% for both groups of forestry professionals, and the proportion of disc trenching had decreased to approx. 10%. The proportions of mounding had increased in both participant and non-participant FOAs compared with the 2006 survey. Mounding was 10% more common among the non-participant forestry professionals. It should be noted, however, that the sample was not identical, e.g., from Lounais-Suomi there were fewer responses.

Table 18. The adoption of self-control measurements of planting density in areas where the planting workers employed by respondents (quality work participant and non-participant) have received planting work education (2007 survey).

Participation in quality work	Participation in planting education	Self-control measurements of soil prep. and planting density Yes, %	No, %	No. of responses	χ^2 -value
Non-participant	Education	33	33	52	2.61
	No education	11	23	26	
Participant	Education	50	31	99	10.44***
	No education	5	14	24	

* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level.

Table 19. Changes in applied practices in the forest regeneration service process (part 1).

Information intended to be measured	Survey year, QM participation			
	2006		2007	
Alternative	Part.	Non-p.	Part.	Non-p.
Increased number of visits to check site and soil characteristics				
Yes (%)	42	36	53	59
I cannot say (%)	11	2	5	6
No (%)	47	62	42	35
No. of responses	123	61	124	80
χ^2 -value		6.46*		1.04
New argumentation in the marketing phase of the regeneration chains				
Yes (%)	58	48	65	51
No or I cannot say (%)	42	52	35	49
No. of responses	125	60	121	79
χ^2 -value		1.4		4.26*
The most common soil preparation method for Norway spruce				
Mounding (%)	50	40	63	73
Patching (%)	32	23	27	19
Disc trenching (%)	18	37	10	8
No. of responses	121	57	124	79
χ^2 -value		7.47*		2.45
The most greatly increased soil preparation method for Norway spruce				
Patch mounding (%)	55	34	70	61
Mounding with ditching (%)	31	34	18	24
Patching (%)	11	22	6	7
Inverting (%)	2	10	6	8
Disc trenching (%)	1	0	0	0
No. of responses	118	59	124	80
χ^2 -value		12.07*		1.79
The most commonly used type of seedlings for Norway spruce				
1.5 year and older	87	92	91	80
One-year-old	13	8	9	20
No. of responses	61	119	116	76
χ^2 -value		1.08		5.01*

Note: “QM. participation” = Participation in forest regeneration quality management. “Part.” = Participant, “Non-p.” = Non-participant. * significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level.

The soil preparation method whose application had increased the most in the context of Norway spruce planting was patch mounding (Table 19). According to the 2007 survey, patch mounding accounted for 70% of responses from participant FOAs, while it accounted for 61% of those from the non-participant FOAs. The second greatest increase was observable in the proportions of mounding with ditching, which had increased more in the non-participant FOAs. The most common soil preparation method used overall and the one whose application had increased the most with Norway spruce were cross-tabulated so that it could be discovered whether any increase in the use of a particular method was different in areas where there were different practices of soil preparation. In those FOAs, where mounding was the most common method used, patch mounding had increased according to 68% of the responses received from participant forestry professionals (Figure 10). In the non-participant FOAs, patch mounding had increased according to 57% of the responses. Increased application of mounding with ditching accounted for 22% of the responses received from participant FOAs and for 31% of those from non-participant FOAs, correspondingly.

The overall development of the proportions of regeneration chains and soil preparation methods applied were later reviewed through the statistics concerning Finnish forestry (Kankaanhuhta et al. 2010, Metinfo Statistical… 2010). Figures 11 and 12 suggest positive trends in the proportions of these indicators in the forestry centres that participated in quality work.

Figure 10. Increased use of soil preparation methods compared with the most common soil preparation methods for Norway spruce in the 2007 survey. For example, if mounding has been the prevailing method during the last five years, how patch mounding (= p. mound.), mounding with ditching (= mound.), inverting (= invert.) and disc trenching (= d. trench.) have been increased among the respondents.

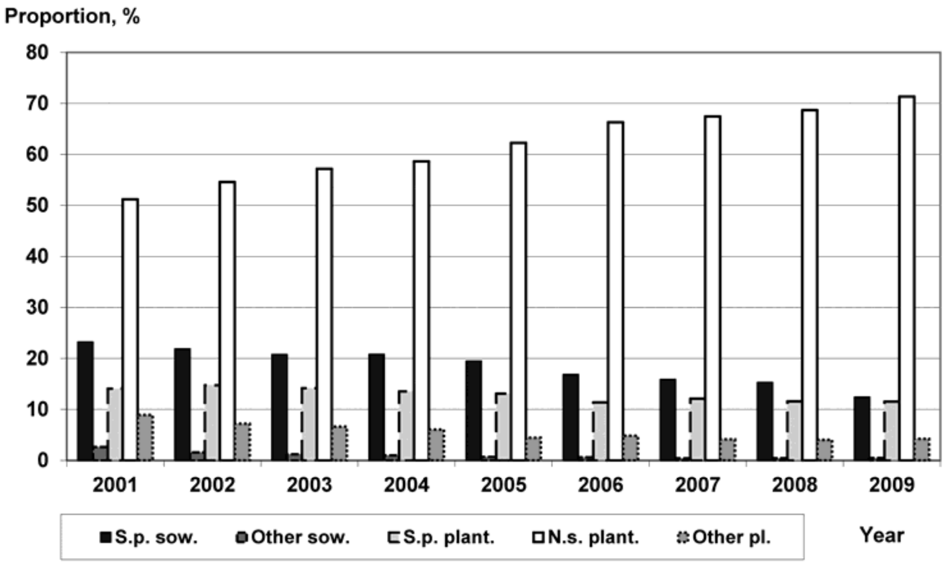

Figure 11. Proportions of regeneration methods by tree species in privately-owned forests in the area of six quality work participant forestry centres in 2001–2009. Redrawn from Kankaanhuhta et al. (2010). Abbreviations for regeneration methods: “S.p. sow.” = Scots pine direct seeding, “Other sow.” = Direct seeding of other tree species, “S.p. plant.” = Scots pine planting, “N.s. plant.” = Norway spruce planting, “Other pl.” = Planting of other tree species.

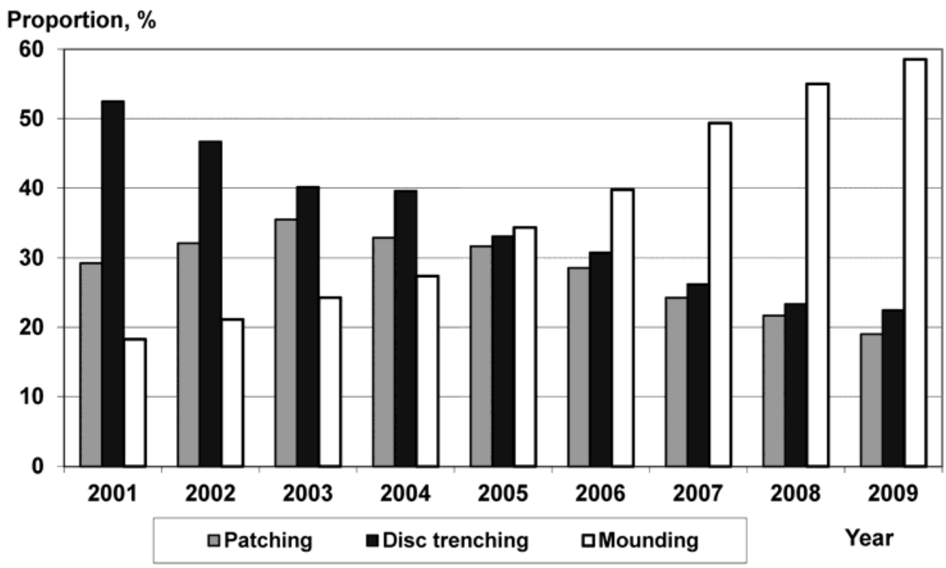

Figure 12. Proportions of soil preparation methods in privately-owned forests in the area of six quality work participant forestry centres in 2001–2009 (Kankaanhuhta et al. 2010).

In the choice of regeneration material sub-process, regeneration material is selected, maintained, and delivered to the regeneration areas. In the case of Norway spruce planting, the most commonly selected types of seedlings were 1.5 years and older. These large containerised seedling types were used by participant forestry professionals 11% more compared with non-participants. The use of 1.5-year-old seedlings had experienced the greatest increase (Table 20). On the other hand, the use of one-year-old seedlings had increased the least. The most notable difference between the groups of forestry professionals was found in the use of two-year-old seedlings. Although, the use of this seedling type had increased 11% more among the participant FOAs, the differences in general were statistically insignificant.

The target densities of seedlings are used in the choice of regeneration material sub-process, when adequate numbers of seedlings are ordered by the forestry professionals. Additionally, the target densities are applied in the regeneration work sub-process when the self-control measurements of planting density are carried out by the planting workers. The mean target densities of Norway spruce planting that were used by participant and non-participant respondents were practically the same. In the case of Scots pine planting, a small but statistically significant difference was found in favour of the participant forestry professionals.

Table 20. Changes in applied practices in the forest regeneration service process (part 2).

Information intended to be measured	Survey year, QM participation			
	2006		2007	
Alternative	Part.	Non-p.	Part.	Non-p.
The most greatly increased type of seedlings for Norway spruce				
1.5 year old	42	49	40	47
Two-year-old	26	18	31	20
Equal amounts	19	23	22	23
One-year-old	13	10	7	10
No. of responses	123	61	121	79
χ^2 -value		2.26		3.22
The completion date for Scots pine direct seeding				
Before 15.5.	4	8	2	4
16.5. - 31.5.	19	35	16	13
1.6. - 15.6.	59	49	56	52
After 16.6.	18	8	26	31
No. of responses	114	51	100	69
χ^2 -value		8.29*		1.40

Note: “QM. Participation” = Participation in forest regeneration quality management.
“Part.” = Participant, “Non-p.” = Non-participant
* significant at 0.05, ** significant at 0.01 and *** significant at 0.001 level.

The analysis of seed quantities in Scots pine direct seeding produced a small but significant difference between the groups of respondents in favour of participant FOAs. The estimated mean for the quantities of seed used by the participant forestry professionals was 313 g per ha (SD = 55 g per ha), and 295 g per ha (SD = 73 g per ha) for the non-participant forestry professionals. In addition, a probable influence of experience in quality work was detected, as the forestry professionals were classified as non-participants, one-inventory forestry professionals, and two-inventory forestry professionals (Table 21). The estimated means for the quantities of seed used were 295 g per ha for the non-participants, 306 g per ha for the one-inventory forestry professionals, and 323 g per ha for the two-inventory forestry professionals. The differences in the quantities of seed proved to be statistically significant.

In the regeneration work sub-process of Scots pine direct seeding, the finishing time point concerning the mechanised sowing of Scots pine was investigated. According to 26% of the participant forestry professionals, mechanised sowing was completed after the 15th of June in the last five years. In the case of the non-participant forestry professionals, mechanised sowing after the 15th of June accounted for 31% of their responses. The differences between the participant and non-participant respondents were statistically insignificant.

The enquiry of existing knowledge regarding the various aspects of forest regeneration services suggested no actual differences between the groups of forestry professionals. Both participant and non-participant forestry professionals possessed adequate knowledge of the economic relevance of good regeneration results. Furthermore, their knowledge of target densities at a stand age of three to five years was sufficient.

Table 21. The quantities of seed used for Scots pine direct seeding according to the experience of quality work.

Survey year	Quality work experience	No. of responses	Mean (g/ha)	SD	F -test value	Significance (p -value)
2006	Non-participant	56	296	74	5.30	0.006
	One inventory	67	297	63		
	Two inventories	58	330	57		
2007	Non-participant	78	295	73	3.04	0.05
	One inventory	71	306	56		
	Two inventories	50	323	52		

“Quality work experience” = Experience of quality work.

6 DISCUSSION

6.1 Assessment of the research

6.1.1 Relevance

By the turn of the millennium, growing concern had risen about the quality of the young stands, while the demands for the cost-efficiency of silviculture were increasing (Hartikainen and Kokkonen 1996, Saksa 1998, Saksa et al. 1999, Harstela et al. 2001). Society was also undergoing change: the structure of forest ownership was changing so that the demand for more developed services was predicted to increase (Hänninen et al. 2011). Furthermore, the proportion of public subsidies for forestry was anticipated to decrease due to the weakening dependency ratio (Niskanen et al. 2008). At the same time, competition began to intensify in the market for silvicultural services, which gradually put pressure on the competitiveness of the nearly monopolistic FOAs.

Quality management was proposed as a potential solution for the predicted challenges in the non-industrial privately-owned forests of Finland (Kalland 2002, Saksa et al. 2002, Kalland 2004, Saksa et al. 2005, Harstela et al. 2001, Kiljunen 2006). It was considered as a successful organisational innovation in mass manufacturing and high-volume services, and its implementation was also demonstrating promise in the forest industry corporation UPM-Kymmene (Garvin 1988, Silvestro 2001, Kalland 2002, 2004, Lillrank 2003a). The standardisation of activities managed in processes, analysis of the statistical variation of systematically measured data and learning from the results of continuous improvement activities have provided the foundation for the improvements of quality, cost-efficiency and productivity (Deming 1986, Ishikawa 1985, Juran and Gryna 1988).

The relevance of the data generated for the different sub-studies of this thesis have to be assessed separately. Since the 1960s, the field inventories, which measure the state and characteristics of young stands, have become a paradigm to obtain information for management and policy making (Article II). However, the inventory systems have evolved according to their defined purpose. In Article III (cost–quality relationship), the collection of forest regeneration cost data – i.e., invoicing information – was defined from the viewpoint of the general quality management theory, in which the customer perspective is emphasised. In studying the effect of quality management interventions on forest regeneration activities in Article IV, the theory for data generation by Donald Kirkpatrick, which was further developed by Claude Bennett, was applied (Bennett 1975, Bennett 1976, Kirkpatrick 1976, Kirkpatrick and Kirkpatrick 2006). Considering the time elapsed since the initiation of this evaluation theory at the end of the 1950s, it may also be considered a well-tested background theory for data creation.

6.1.2 Generalisability of results

In the research for management and business, the utility and applicability of theories created are a major concern. These research needs may be met through the generalisation from theory to description (Lee and Baskerville 2003). In this type of research, a theory confirmed in one setting is generalised and applied to descriptions in other settings. For instance, the quality management system and inventory method that were developed for the operational environment of forest industry companies' own forests were chosen as the starting point for the quality management interventions in the non-industrial privately-owned forests (Kalland 2002, Saksa et al. 2002, Saksa et al. 2005). This thesis was conducted in the operational environment of FOAs providing forest regeneration services for the NIPF owners in the area of six forestry centres at the turn of the millennium. The operational environment and activities of the FOAs may be considered to correspond to the average FOAs of Southern Finland reasonably well. According to the results of this thesis, the generalisation of the above-mentioned management system by UPM-Kymmene Corporation and its application and further development in a new setting was to some extent successful.

Generalisation from concepts to theory involves generalising variables, constructs or other concepts to theoretical propositions that constitute a theory (Lee and Baskerville 2003). The initial construction of the theoretical framework of quality management for this thesis generalised from concepts to theory (Article I). The theoretical framework of this thesis consisted of the main elements of quality management defined by the main authors – Deming, Juran and Ishikawa (Ishikawa 1985, Deming 1986, Juran 1989, Deming 1994, Hackman and Wageman 1995). At the general level, these elements included systems theory, control of statistical variation, theory of hypothetic–deductive knowledge creation and learning, and psychology (Gitlow 2001). In addition, the findings of Silvestro (2001) and Lillrank (2003a, 2003b) on the challenging implementation of quality management in those fields, where the assumptions of standardised mass production or high-volume services in the free markets are not completely valid, were considered. Finally, the contributions of marketing and customer behaviour research were recognised by acknowledging the requirements of interactive and perceived quality (Grönroos 1982, 1998, 1999, Lillrank 2010).

The statistical – sampling-based – notion of generalisability has to be assessed separately. The FOAs volunteered for the quality management inventories and interventions in order to improve their forest regeneration activities (Articles II and III). Correspondingly, they represented neither a random nor systematic sample of the forestry centres. In this sense, even greater variation in the results of regeneration activities could be expected if the hypothetically less motivated FOAs would have been included. Nonetheless, the coverage of the inventories has to be judged substantial. Considering the data of the quality control inventories and 2007 mail survey 2007 for the effect of interventions, the study material obtained represented the conditions of Southern Finland at that particular time reasonably well (Article IV). On the other hand, Article III dealing with the cost–quality relationship was a case study consisting of a maximum of 18 municipalities within 12 FOAs. Thus, the generalisation of the statistical estimates of this study to apply to other parts of Finland is questionable. Even more clearly in this case, the voluntary participation of the FOAs may indicate higher-than-average motivation and greater concern for the competitiveness of services. This may imply that even greater variation in the costs and quality of the services could be expected. However, the previously mentioned issues may be judged to have a minor effect on the cost–quality relationship.

In the first round of the quality control inventories, the full coverage of the regeneration areas under the supervision of a certain forestry professional within each municipality was recommended (Articles II, III and IV). In those municipalities or FOAs which participated in two inventory rounds, stratified systematic sampling was sometimes applied within the stands supervised by every forestry professional in given municipality. The full coverage of the stands under the supervision of the forestry professionals was considered to provide the most credible feedback on the results of activities for local actors. According to the statistical theory for sampling, however, a smaller sample would have provided adequately reliable feedback.

The main type of generalisation in this thesis was analytic generalisation, in which generalisation from descriptions to theory was utilised within the research framework (Yin 1994, Lee and Baskerville 2003). This class of generalisation also includes a theory positing new variables to be measured and relationships to be found that would explain the results of field experiments. In this context, descriptions include measurements and observations – i.e., quality control measurements, cost data, mail surveys, registry data and semi-structured interviews – and the relationships discovered.

The quality management frameworks adopted to serve large-scale forest owners and the one constructed in this thesis form a continuum, the applicability of which may also be assessed internationally. In the other end of the continuum, there are state-owned forests and other large forest owners who may buy silvicultural services from free markets. In the case of these organisations, forest regeneration services may be more standardised internal services. These internal services may be improved fairly straightforwardly through conventional principles of TQM used also in the mass production of goods. Furthermore, it has to be emphasised that in some forest industry companies the focus of productivity improvement may no longer be on the quality of operations. Instead, the focus has switched to the speed and flexibility of operations (Ferdows and DeMeyer 1990, Gummesson 1998, Slack et al. 2010).

In the opposite end of the continuum, there are small-scale non-industrial privately-owned forests. The quality management of forest regeneration services for these heterogeneous clients with various values and wishes require a more elaborate approach as shown in this thesis. In such instances, technical and interactive quality still requires considerable attention without forgetting the eventual perceived quality of service (Grönroos 1982, Lillrank 2010). The assessment of local site conditions and negotiation of both available methods and targets – e.g., the number of seedlings for the outcome – with the forest owner establishes the foundation for interactive quality. In this sense, this framework is applicable to serve those forest owners who agree with the target densities used in this study as well as those having different targets in other contexts. Furthermore, as the transaction context and operational environment of the service providers have continued to change substantially in Finland, the adoption of this kind of framework will be even more recommendable.

On the whole, the tentative framework for quality management of forest regeneration activities may be considered applicable for the conditions in non-industrial privately-owned forests of Southern Finland (Article I, IV), but has to be tested further and refined to suit the conditions of Northern Finland and, e.g. other parts of Scandinavia and Baltic countries. In addition, the varying results on the relationships between the costs and quality of forest regeneration services were logical with respect to the pricing theories and diverse findings on cost–quality relationships in other fields of business (Garvin 1988, Zeithaml et al. 2009, Article III). The analysis of the cost–quality relationship also provided experience with the statistical methods used: multilevel models will be preferred over the conventional coefficients of correlation since the correlation structure of the study material may be better accounted for.

The implementation of quality management may vary, and due to the complexity of this management doctrine, all of the prime elements may not be controlled in the generalisation of this framework towards local descriptions of practices. Considering the main elements of this doctrine in the quality work, this thesis could provide little empirical evidence on the actual organising of activities and defining of responsibilities between the local actors. For instance, the promotion of greater decisive power and responsibility of the employees over their tasks were practically out of the reach of data collection in this thesis. Therefore, it was not certain whether the autonomy, freedom and responsibility of the local actors were fully facilitated in the implementation of quality management in the FOAs. However, there was no basis for questioning the recommendations of Theory Y and related assumptions of quality management, or the experience obtained from the quality management system of UPM-Kymmene Corporation (Baker 1988, Kalland 2002, 2004, McGregor and Cutcher-Gershenfeld 2006).

6.1.3 Validity and reliability

Regardless of the system for data generation, the validity and reliability of the measurements have to be determined (Tashakkori and Teddlie 1998). The assessment of validity involves the demonstration that the theoretical constructs, e.g., the quality of forest regeneration results, have actually been measured through the empirical indicators chosen (Dröge 1997). Tuomivaara et al. (1994) characterise valid data as data which correctly describes the relevant features of the object. In practise, it may be asked (Tashakkori and Teddlie 1998): “Am I truly measuring what I intend to measure rather than something else?” The assessment of reliability, on the other hand, demonstrates the extent to which the measurement of those indicators yields consistent results when the process of measurement is repeated in one way or another (Dröge 1996, Tuomivaara et al. 1994). For example, control measurements were arranged for the measurement personnel of the quality management inventories and the measurement instruments were crosschecked (Saksa and Kankaanhuhta 2007). In practice, it may be asked (Tashakkori and Teddlie 1998): “Assuming that I am measuring what is intended, is my measurement without error?”

The design of the quality control inventory method (i.e., timing, sampling and performance variables) has been selected according to the results of both experiments and inventory studies (e.g., Yli-Vakkuri et al. 1969, Pohtila 1977, Pohtila 1980, Räsänen et al. 1985, Eid et al. 1986, Saksa 1992, Kinnunen 1993, Kalland 2002). The relevance and validity of data acquisition as well as the performance variables measured have to be considered adequate for the operational management systems of silviculture (Hämäläinen and Räsänen 1993, Kalland 2002, Saksa et al. 2002, Saksa et al. 2005, Saksa and Kankaanhuhta 2007).

The operational inventory systems for management, however, do not satisfy the criteria for the theory of data generation for experimental purposes, in which the purpose is, e.g., the discovery of new causal relationships and mechanisms. In the experimental research settings, the purpose is to design the experiments so that the data obtained will be balanced. In practice, this means that, e.g., an equal number of observations will be treated with the methods selected and comparable circumstances will exist for the implementation all those methods. In this sense, the experimental settings provide sounder evidence of the prevailing relationships in order to establish more truthful theories. However, it will not be guaranteed that new knowledge or innovations will be adopted and implemented in such a manner that the results of local activities actually improve. Due to the analysed results of the operational measurements, the relevance of some research problems intended for experimentation may even change or some of the research questions for experimental studies potentially have to be altered.

In the inventory method developed for quality management, the time scale is compromised as the results of forest regeneration activities are measured (Kalland 2002, Saksa et al. 2005). In order to give immediate feedback to the forestry professionals, it would be even better to conduct the inventory instantly or one year after the regeneration activities. This has even been tested locally in the FOAs as a performance indicator of the planting sub-process. However, depending on the operations chosen and local site and weather conditions, the quality of the outcome may be assessed only a few years later. The moment of inventories was set at three years after planting, four years after direct seeding and five years after the activities of natural regeneration, i.e., soil preparation. However, only planting and direct seeding were covered in this thesis. At this stage of stand development, the result of forest regeneration activities could be verified with certainty, and the development of broadleaves and sprouts had not yet significantly disturbed the results (Saksa 1992, Kalland 2002, Saksa et al. 2005).

In general, the definition of a good-quality regeneration result has to recognise the prevailing ecological and economic circumstances and the requirements of forest owners and stakeholders (Articles I and III). In an ideal case, agreement is reached in the marketing of the regeneration chain, and resulting targets may be used as the indicator of interactive quality (Lillrank 2010). At the beginning of 2000, a good-quality result of Norway spruce planting was defined as 1600 crop-trees per ha. This definition was determined for three main reasons (Saksa et al. 2005). First, the recommended densities of planting were 1400–1800 Norway spruce seedlings per ha at the end of the 1990s (Luonnonläheinen metsänhoito … 1994). Second, a certain proportion of mortality was anticipated. Third, at this early stage, the supplementary deciduous seedlings were not counted as crop-trees. However, a trend of increasing target density to 1800 crop-trees per ha has been observable later in the 2000s. The definition of a good-quality result for Scots pine direct seeding was set at 3000 pine seedlings per ha. This target was determined in order to enable growing of saw timber of high quality (Varmola 1996). In addition to the mean densities of young stands, the number of treeless sample plots has been used as an indicator of the regeneration result (Pohtila 1977, 1980, Saksa 1992, Saksa and Kankaanhuhta 2007). This indicator demonstrates how well the available space for the seedlings is utilised, or in other words, the degree of clustering present.

The systematic regular sampling grid with approx. 15–20 sample circular plots was used in the stands inventoried (Articles II and III). Since the numbers of sample plots were not equal, there was a hypothetical risk for sampling error at the stand level. However, this sampling size provided 5–20% accuracy for crop-trees depending on the irregularity of spacing in the regeneration area (Eid et al 1986, Hämäläinen and Räsänen 1993).

The costs of regeneration recorded were the actual ones originating from the invoicing registries of the FOAs (Article III). This represents the real costs incurred by the forest owner for the services ordered. These costs were not comparable to the unit costs compiled for the Finnish Statistical Yearbook of Forestry (2004) due to differences in the practices of recording the unit costs (e.g., overheads including planning and supervision). However, there was one similarity, which indicated the difference in cost levels between the different forestry centres. This was one of those hypothetical differences between the municipalities, which could be taken into account using multilevel models.

The evaluation of the effect of quality management interventions on the activities of forest regeneration covered the municipalities in the area of six forestry centres reasonably well, and the study material has to be considered adequate for the circumstances of Southern Finland (Article IV). The forestry professionals who participated in the interventions were given an opportunity to rank the main reasons for the inventory results, which were covered, e.g., in the feedback meetings and project report (Saksa and Kankaanhuhta 2007). Furthermore, they were allowed the chance to list the main objectives that they had set in light of the feedback. Comparing the reasons for the inventory results obtained and the objectives of the main survey questions, the content validity of these questions could be judged as good.

The FOAs that did not participate in the quality management interventions could only be considered to be a nominal "control" group when the effects of those interventions were evaluated. In the first place, quality management is only one approach among many for management and facilitating change in organisations, and the non-participant FOAs may have had other development projects in progress. For instance, in some FOAs there may have been projects aimed at developing cost-efficient service concepts for silviculture (Harstela et al. 2006). In addition, the educational sessions arranged by the regional Forest Owners' Unions or forestry centres may have encouraged some improvement interventions in some of the non-participant FOAs. Finally, the project report produced by Saksa and Kankaanhuhta (2007) may have affected the knowledge and attitudes of the non-participant forestry professionals since it was sent to the FOAs more than two months before the 2007 survey.

The effect of quality management interventions was studied through two mail surveys; the first in 2006 and the second in 2007 (Article IV). The first one was a pilot study with a smaller sample size. The latter occurred one year after the end of the interventions in order to allow all participants to initiate changes that were considered necessary. After testing the questions and forming the baseline for comparisons in the 2006 survey, the repeatability of the main survey (2007) may be rated as relatively good. As the reliability of the main questions was analysed further, a number of challenges surfaced. It was plausible that the responses of the non-participant forestry professionals were more "optimistic" with regard to the predominant practices of forest regeneration because no measured feedback was made available to these FOAs. A further challenge was related to the greater sample size of the 2007 survey (i.e., the target groups were not identical), which caused deviation in the proportions of the variable classes. On the other hand, some interventions were still made after the 2006 survey, and a number of differences could even be expected due to the elapsed time (two growing seasons).

6.1.4 Assessment of the causes of cost–quality relationships

The implementation of forest regeneration activities was studied in the context of the case study of cost–quality relationship (Article III). The parameter estimates of the multivariate multilevel models were logical compared with the models presented in Article III. In the case of the sub-model for planted Norway spruce seedlings, additional information on the seedlings delivered and charged for was available. Although this estimate was statistically significant, it was unexpectedly low. This may indicate either errors in planting work or low quality of information for this particular variable: the seedlings had not ended up in the designated areas of regeneration. The cost of regeneration for Norway spruce planting was influenced logically by the selection of soil preparation method, type of seedlings and number of seedlings. The models revealed that site fertility and soil texture type were not considered in the planning and execution of service operations, especially in the

Assessment and Algorithm phases (Article I). Challenging site conditions – e.g., OMT site type or fine soil type – did not increase the regeneration costs in Norway spruce planting. In this sense, even greater monetary inputs for tackling these challenging conditions would have been expected. Increasing the regeneration stand area reduced the unit cost of regeneration, which is logical in view of the hypothesised equal cost-based pricing of the FOAs. If the fixed costs of soil preparation, planting work and supervision had been taken into account along with stand size, the cost for stands of 0.5 to 2.0 hectares should have been higher, and the cost of larger stands should have been slightly lower (Rummukainen et al. 2002).

In the case of implementation of Scots pine direct seeding, the consequences of poor selection of regeneration method and tree species could be seen via the multilevel multivariate model. The selection of this regeneration chain for too fertile site types (MT or OMT) or fine mineral soil decreased regeneration result significantly. The influence of site type, soil texture, stoniness, and method of soil preparation was consistent with the results of Article II and those of Miina and Saksa (2008). These factors explained differences in the regeneration results obtained by actors in different municipalities. Furthermore, the hypothesised influence of more difficult local site conditions on the increase of regeneration cost was not observed. Increasing the quantity of seed improved the regeneration result; this suggests that the previously observed better results of mechanised sowing compared with manual sowing were obtained on account of the potential of the machines to sow greater quantities of seed (Heikinheimo 1932, Miina and Saksa 2008, Pohtila and Pohjola 1985, Article II). Increasing the stand area reduced the unit cost of Scots pine direct seeding in a similar manner to that seen with the planting of Norway spruce. The fixed costs of regeneration operations were not considered in pricing and prices seemed to be almost equal for all members of FOAs. This emphasises the need for Activity-Based Costing (ABC) not only in tracking the costs of poor quality, but also in the calculation of cost-efficient stand sizes for the selection of regeneration methods.

6.2 Theoretical contribution

The assumptions of quality management doctrine for mass manufacturing and high volume services in free markets are not completely valid in the context of professional forest regeneration services for non-industrial private forest owners. As it has been found by Silvestro (2001) and Lillrank (2003a), the general theory of quality management has to be adjusted to different fields of business with respect to the varieties of outcomes required by the client, after which the challenges in the statistical variation and standardisation of the production may be tackled. The applicability of Lillrank's (2003a) classification of the production processes to standard, routine and non-routine proved to function well in this context of forest regeneration activities. Focus on the fitting varieties of forest regeneration service and consistent implementation provided a starting point for further efforts.

The evidence concerning the mechanism, which the jointly analysed feedback on the results of the quality control inventories launched, has to be considered as another contribution. This process of dialogue and reflection included the CEOs, forestry professionals, researchers, and depending on the case, also inventory personnel, forestry workers, entrepreneurs, and representatives of forest owners and forestry centres. The measured and jointly analysed feedback formed a common object and purpose of activities for the stakeholders, which they were able to reflect on. Finding this common object may be considered as a sound starting point for the improvement of the interactive quality of these services (Lillrank 2010). This shared view of the service will be essential in the further problem solving and development of forest regeneration activities, which acknowledge the basic elements of quality management. Some of these findings may be explained through behavioural sciences and organisational learning theories (Vygotsky 1978, Argyris and Schön 1978, Engeström 1987, Senge 1990, Nonaka and Takeuchi 1995, Virkkunen et al. 1997). Furthermore, there was an indication that the general framework of quality management requires further contribution from research concerning, e.g., customer behaviour and relationship marketing, flexible management of networked supply chains, cost accounting, and other areas of service operations management (Christopher 1998, 2000, Grönroos 1999, 2010, Slack et al. 2010, Salvendy and Karwowsky 2010).

The tentative framework for quality management of forest regeneration activities in non-industrial privately-owned forests was created for further testing and development. The chain of forest regeneration activities was analysed from the viewpoint of the "Assessment–Algorithm–Action" sequence through conceptual modelling of service processes. The high quality of forest regeneration services may be obtained by standardising these service processes into routine processes (Articles I and II). In addition, considerable potential for improvement of cost-efficiency of forest regeneration activities was demonstrated through the analysis of cost–quality relationships (Article III). This potential may be assessed by comparing the variation in results between UPM-Kymmene's and privately-owned forests in the beginning of quality work. Considerable variation in regeneration results was observed between different units of UPM-Kymmene's organisation early on (Kalland 2002, 2004). Correspondingly, considerable variation existed in both the regeneration results and cost of services between actors at various levels in privately-owned forests (Articles I–III).

The solutions found for the mitigation of statistical variation in the regeneration results of UPM-Kymmene Corporation were nearly analogous to those found in the FOAs (Saksa et al. 2005). A need for increasing the proportion of Scots pine direct seeding compared with natural regeneration and planting was observed. Furthermore, a need for increasing the proportion of Norway spruce planting was acknowledged. In addition, raising planting densities and switching to mounding when preparing soil were among the changes implemented. As shown in Figures 11 and 12, the overall development of the proportions of forest regeneration chains and soil preparation methods in privately-owned forests indicated a positive trend in the forestry centres participating in quality work (Kankaanhuhta et al. 2010, Metinfo Statistical… 2010). The above-mentioned figures are, however, suggestive since the classification of participation used in Article IV could not be applied any more due to the fusions of municipalities and FOAs.

The rules for improvement diagnostics of routine and non-routine processes proposed by Lillrank (2003a) were also supported by the evidence obtained in this thesis. The defects related to variation of regeneration results have to be separated from the errors that are related to different service varieties: "Are the right chains of regeneration and methods selected, and are they implemented in the proper manner?" The practical implications of this thesis are mainly in this area. Furthermore, the precise part of the "Assessment–Algorithm–Action" sequence from which the problems of regeneration activities originate should be analysed. In the various sub-processes of the forest regeneration service process, the cases from different parts of the AAA sequence were clearly demonstrable (Article I). However, depending on the service provider, the implications according to this analysis may vary considerably. In addition, it should be diagnosed whether the situation and local circumstances were manageable through the routine or non-routine service process. In this case, the defined targets of forest regeneration service varieties have to be explored in order to find out whether the targets set are achievable in a consistent manner, or new varieties of services with different outcomes should be designed. Although, it is recommendable to try to avoid non-routine processes, and to define exact target and response categories for the routine processes, there may be cases in which the methodologies for improving non-routine processes and double-loop or even expansive learning are required (Argyris and Schön 1978, Engeström 1987). For instance, the revisions of the Forest and Forest Management Association Acts may require these kinds of improvement activities.

6.3 Practical implications

The results of this thesis provide strong evidence in favour of systematically measured and jointly analysed feedback on the results of forest regeneration activities. In practice, this means that the supplier–customer chains of forest regeneration services have to be facilitated with tools and opportunity to jointly analyse the feedback on the quality pursued. In the quality work, the next recommendable steps will be the standardisation of the forest regeneration activities into routine processes, sharing of the knowledge regarding best forest regeneration practices observed, freedom of choice in the implementation of actions and operations, and at the same time, responsibility for the quality of the results (Baker 1988, McGregor and Cutcher-Gershenfeld 2006).

Forest regeneration activities were constructed into a conceptual model, which demonstrates the anticipation of the risks in the design of forest regeneration services (Article I). Furthermore, the challenges with the greatest potential for improvements were detected (Articles II and III). The regeneration results varied between the FOAs in both Norway spruce planting and Scots pine direct seeding. A certain proportion of the statistical variation could be attributed to various levels of hierarchy from sample plot and stand level to forestry professionals, who were working in the FOAs. Depending on the local and regional circumstances at the forestry centre level, this may indicate different kinds of activities for the continuous improvement of these services. The overall results indicated that the selection of different methods for sub-processes and the way they were implemented were the most common factors influencing the regeneration results (Articles II and III).

In the planting of Norway spruce, the most important factor explaining the regeneration result was the selection of a proper soil preparation method. Mounding produced a better outcome compared with patching and disc trenching. Additionally, the site and soil characteristics were other important factors that influenced the regeneration result. Planting of Norway spruce on MT site type produced a slightly better results compared to more fertile OMaT and OMT sites. Correspondingly, planting on VT and less fertile site types produced slightly weaker results with respect to the MT sites. Furthermore, planting on fine-textured soil and on peat-land provided weaker regeneration results compared with medium coarse mineral soil. Depending on the case, these challenging site conditions may be compensated for, for instance, selecting older seedlings, increasing the number of well-prepared planting spots and number of seedlings planted.

In the case of Scots pine direct seeding, the selection of this method on too fertile site types was the single most important reason for the poor outcome of this service variety.

Sowing on VT and less fertile sites produced the best results. In addition, the prevailing soil texture type was another site feature worth assessing. Fine-textured mineral soil and peatland yielded poorer results relative to medium coarse mineral soil. On the other hand, coarse mineral soil slightly increased the number of pine seedlings compared to medium coarse mineral soil. Furthermore, excessive wetness diminished the result of Scots pine direct seeding by almost one-third.

The improvement potential of the cost–quality relationship forest regeneration services was demonstrated in a case study. There was considerable variation in both the costs and quality of service outcomes between the municipalities, which were used as the operational units for the FOAs. Those service providers, who had selected fitting methods and implemented them with proper consideration of challenging site and soil conditions, were able to obtain good regeneration results. However, in many cases there was room for improvement.

In the case of Norway spruce planting, the costs were only weakly related to quality. This relationship may be demonstrated with an investment of 100€ that would increase the number of crop-trees by only 33 per ha. In the case of Scots pine direct seeding, there was a significant positive correlation between the cost and number of pine seedlings. Correspondingly, an extra investment of 100€ increased the number of pine seedlings by 654 per ha. The selection of Scots pine direct seeding in suitable site conditions proved to be a noteworthy issue also in this case study. As expected, site fertility and soil texture type as well as soil stoniness influenced the outcome of regeneration operations.

The further search for root causes behind the cost–quality relationship of Norway spruce planting and Scots pine direct seeding produced unexpected results. The hypothesised influence of more challenging site fertility and soil texture types on the cost of regeneration activities did not emerge as significant. There was no extra investment in regeneration activities, for example, on more fertile sites or fine soils. This indicates a considerable need for improvement of the assessment and algorithm phases of these service processes. In practice, these results indicated that setting targets for the types and quantities of regeneration material, the selection of methods, and implementation of operations will require further attention in the future. In the best case, forest regeneration services were classified as a routine process, hence there is potential for the standardisation of these service varieties.

The effect of quality management interventions on the activities involved in the forest regeneration services was encouraging and fruitful. These interventions initiated a process of change in the participant service organisations. The forestry professionals were able to obtain root causes for the outcome of the activities, which they had been supervising. Based on the measured and analysed feedback, the three main reasons for the quality obtained were the soil preparation method selected in the context of Norway spruce planting, artificial regeneration of Scots pine on too fertile sites, and insufficient planting densities. Three-fourths of the participant forestry professionals set objectives for their future activities. These objectives were consistent with the overall analysis results of Articles II and III. The most common objectives set by the participant forestry professionals included changing soil preparation methods, selection of an appropriate chain of regeneration methods for site conditions, setting targets for planting densities and execution of regeneration work, and selection of seedling material best suited for the site conditions in question.

Quality management interventions initiated a diffusion process of more effective soil preparation innovations for Norway spruce planting. Especially the adoption of excavator-based mounding methods was most noteworthy. This could be detected in the greater increase in the number of excavator contractors among the quality work participant FOAs. Furthermore, in the participant FOAs, the soil preparation contractors had acquired more soil preparation equipment than those under the supervision of the non-participant FOAs. Patch mounding (upturned humus forming a flat mound with double humus layer) was the method of mounding whose application increased the most. Those soil preparation operators, who worked for quality-work participant FOAs, had also participated more frequently in educational sessions of soil preparation.

The forestry professionals who had participated in quality work used significantly more 1.5-year and older Norway spruce seedlings than non-participants. In general, the use of 1.5-year-old seedlings had increased the most, but the greatest difference between the participants and non-participants was observed in their use of two-year-old seedlings. The use of this seedling type had increased more among the participants. The target densities for planting used by the participant and non-participant forestry professionals were at a good level based on the silvicultural recommendations (Hyvän metsänhoidon … 2001, 2006). Correspondingly, the quantities of seed used in Scots pine direct seeding were at a good level among both groups of forestry professionals. However, those forestry professionals with a longer history of quality work tended to use more seed.

The forestry professionals who had tested the usefulness of the forest regeneration quality management inventories were more interested in adapting this management regime compared with the non-participants. In addition, the effect of quality management interventions on the training of planting workers of the participant FOAs was at a higher level compared with non-participant ones. The planting workers of participant FOAs had taken part in educational sessions significantly more. In addition, the self-control measurements of soil preparation and planting density had been adopted more frequently in the participant FOAs. Among these FOAs, the planting education also seemed to enhance the adoption of self-control measurements as a quality tool. This suggests that successful adoption of this kind of new quality management tool may require multiple interventions by different change agents.

The overall understanding of the forestry professionals regarding the economic significance of a good regeneration result and their understanding of the most appropriate regeneration methods were demonstrably at a good level of competence. However, the improvements in the assessment of site conditions, negotiations with the client, and selection of proper regeneration methods for various site conditions could not be verified through mail surveys at the moment of Study IV. Many of the results of this study indicated that difficulties still seemed to exist with implementing the general level of knowledge into consistent practices.

6.4 Needs for further development

The political decisions and changes to forest and FOA legislation, economic situation, change in societal structure, emerging technological innovations, and environmental issues are creating pressure on the conventional forest regeneration service providers. In a broader context, this also covers other silvicultural services integrated into forest property management services. There will be a growing need to expand the research focus from quality and dependability of operations to speed and flexibility without forgetting the requirements of customer relationship marketing (Grönroos 1998, 1999, 2010, Gummesson 1998). Frameworks for fast and flexible co-creation of networked value-adding silvicultural services have to be constructed and tested (Stalk and Hout 1990, Boynton et al. 1993, Naylor et al. 1999, DaSilveira et al. 2001, Slack et al. 2010, Victor and Boynton 1998).

The focus on the technical quality of new service concepts, however, has to be maintained. New information on modelling and standardising of forest regeneration operations (i.e., controlling the statistical variation), cost accounting (i.e., Activity-Based Costing), and design of services is needed in order to allow implementation of cost-efficient high-quality services. In addition, in the future, it is necessary to obtain more knowledge concerning information-intensive decision support and management techniques that are able to utilise the operational databases, forest management and mobile enterprise resource planning systems of the service providers. This also provides opportunities for creating service packages with greater added value, which recognise the systemic perspective of cost-efficiency as several silvicultural methods are combined in the long run.

The change in the nature of silvicultural work will spawn another area for research. There will most probably be new innovations in mechanisation of operations, nursery technology and seedling production as well as in the division of work, e.g., networked supply chains. These issues are already areas of research with linkages to quality management on their own. In addition, as so many elements of the service systems are potentially changing at the same time, there will be a need for research, which integrates productions systems and human behaviour. These challenges will require knowledge that is obtained through action research or developmental work research, which utilises the theories of behavioural sciences and sociology (Argyris and Schön 1978, Argyris et al. 1985, Engeström 1987, 1996, Virkkunen et al. 1997, Sannino et al. 2009). A probable challenge will be on where the conventional notions of the stakeholders regarding the meaning, purpose and nature of work will not be valid any more. Otherwise, the accumulating changes may burden the forestry workers, entrepreneurs, machine operators and forestry professionals in excess. This will decrease the level of services and the state of young stands in the long run.

The challenges and sophistication of the forest regeneration services will, by no means, diminish in the near future. The most contradictory issues will, however, also provide opportunities. On this path, the basics – mitigation of the statistical variation caused by the main factors – have to be tackled first. Then, more elaborate tools for service concept development and quality control may be developed to meet the needs of the service providers. The ultimate vision for the research and development of silvicultural services will be the provision of forest property management services that offer the defined added value to the forest owners – e.g., 3–4% return on investments. The ease of use will be the key issue here; the selection of the methods and their implementation will be the responsibility of the professionals.

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