Efficiency and Safety in Self-employed Family Forestry

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Cover: The future forest owner Erik Nordstrand in practice with a chain less mock-up chainsaw.
Photo: Erik's cousin Ola Lindroos

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Abstract

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Self-employed family forestry refers to forestry work conducted by the owners themselves, either alone or with assistants, on their forest holdings. Despite the term self-employed, most persons are not economically dependent on the work, which is mainly conducted in their leisure time. In Sweden, half of all work time conducted and most of the lethal accidents in forestry occur in self-employed family forestry. Nevertheless, knowledge about the sector is limited. The objective of this thesis was to examine efficiency and safety in self-employed family forestry.

Self-employment in family forestry was found to be common and there were no signs that it is likely to decline in the near future. Two thirds of the forest owners were to some extent self-employed in cutting, extraction, planting and pre-commercial thinning. Self-employed owners differed in a number of demographic factors (e.g. age and sex) compared to other forest owners. Extensive sales of suitable equipment indicated no decline in the near future. Firewood-processing was also found to be common in family forestry, as were related accidents. Exposure in terms of work time explained more of the accident occurrence than numbers of active persons, age or sex, and wedge splitter machines were associated with a disproportionably large number of accidents in terms of hours used.

Since manual tree felling causes the majority of lethal accidents in forestry, a method was developed to enable evaluation of felling tools' capacity to force trees to fall after cuts have been made in the stem. The method proved to be suitable for the intended purpose, and its practical utility was theoretically demonstrated in the assessment of a tools' capacity to deal with trees with an unfavourable inclination. In addition, the impact of increased mechanisation of small-scale firewood-processing was analysed in an experimental study and was found to improve efficiency by 25-33%.

It is argued that self-employment is important for Swedish forestry, especially for the future voluntary supply of raw material from family forests. Hence, self-employed family forestry deserves encouragement and further attention should be paid to the activity and the conditions that affect it in order to increase efficiency and safety.

Keywords: Small-scale forestry, manual forest work, firewood processing, tree felling, NIPF, accidents, forestry equipment, questionnaires, comparative time study, Sweden.

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Appendix

Papers I-IV

This thesis is based on the following papers, which will be referred to by the corresponding Roman numerals:

I. Lindroos, O., Lidestav, G. and Nordfjell, T. 2005. Swedish non-industrial private forest owners – a survey of self-employment and equipment investments. *Small-scale forest management, policy and economics* 4(4), 409-426.

II. Lindroos, O., Gullberg, T. and Nordfjell, T. Torques from manual tools for directional tree felling. (Submitted manuscript).

III. Lindroos, O., Wilhelmson Aspman, E., Neely, G. and Lidestav, G. Accidents in family forestry's firewood production. (Submitted manuscript).

IV. Lindroos, O. Efficiency in small-scale firewood processing. (Manuscript).

Introduction

Background

Family forestry

Forests often belong to private individuals in many countries around the world and it is the dominant form of ownership in Western Europe (Harrison, Herbohn & Niskanen, 2002). This type of ownership and the associated management of forests are known by many names, e.g. non-industrial private forestry (NIPF), farm forestry, smallholdings, wood-lots, and recently the term small-scale forestry has been frequently used (Harrison, Herbohn & Niskanen, 2002). However, in this thesis this mode of forest ownership and management are called *family forests* and *family forestry*, respectively. The reason for not using small-scale forestry is mainly due to the risk of confusing management with technological criteria (discussed below), and (to a lesser extent) to the fact that holding size was not a discriminator in the studies. A feature shared by all of the mentioned terms is that they are intended to distinguish private individuals' ownership and management from the industrial equivalents. The dichotomy is not clear cut and, furthermore, varies between countries. However, the general difference is that industrial forestry involves a corporate body and the main objective of forest management is to optimise profitability (i.e. timber production). In contrast, management objectives for family forests reflect their individual owners' preferences and often involve goals other than maximising economic returns. Family forest owners in general are widely acknowledged to be interested in their holdings for both economic and other reasons (e.g. Kurtz & Lewis, 1981; Bliss & Martin, 1990; Kline, Alig & Johnson, 2000; Hugosson & Ingemarson, 2004). Regardless of the form of ownership, forest operations (e.g. harvesting, extraction, pre-commercial thinning and planting) can be conducted in diverse ways and are often dichotomized into the use of large-scale and small-scale forest technology. Differences are further discussed below under the *Mechanisation* heading. In the Nordic countries, small-scale forest technology is generally exclusively used in family forests, while large-scale technology may occur in either family forests or forests owned by corporations. The prevailing use of small-scale forest technology is in self-employment, which refers to forestry work conducted in family forests by the owners or their assistants (e.g. family members and relatives).

Sweden's 11.5 million ha of family forest consists of 239,000 holdings, owned by 354,000 individuals (National Board of Forestry, 2004). Family forests constitute 51% of the country's forest land and account for 58% of the wood increment (National Board of Forestry, 2004). Hence, in Sweden, as in many other countries, family forestry has a major impact on the forest industry and the country's economic development. It is, thus, understandable that structural changes and behaviour among family forest owners' have been subjects of a large body of research. Studies on family forest owners' objectives have been reviewed, for example, by Beach et al. (2005) and Ingmarson (2004). Similar studies focusing on the self-employed forest owners' situation are, however, less common.

Self-employment

In Sweden, self-employed forestry has a long tradition, rooted in the self-sufficient agrarian society of previous centuries (Törnqvist, 1995) while firewood production dates from mankind's first use of fire. The term self-employment can give false impressions of people who run their own business for a living, such as self-employed farmers or craftsmen. However, self-employed forestry in Northern Europe seldom provides a living for the people involved in it. Instead, it is generally conducted in leisure time and often makes a limited contribution to their income (Törnqvist, 1995; Ziegenspeck, Hardter & Schraml, 2004). In a society where most people are gainfully employed, these conditions have several direct implications for the way the work is conducted. Firstly, the activity is self-paced and conducted for the workers' own benefits. Secondly, the absence of any employer-employee relationship excludes governmental control, and it receives little attention from market players because of the absence of economic turnover. It should, however, also be kept in mind that for some of the forest owners, the self-employment substantially contributes to their living. For those, it is often a complement to other activities, of which farming is the most commonly cited in both Sweden and Finland (Hämäläinen & Kettunen, 2001; Lidestav & Nordfjell, 2002).

Owning a forest holding implies a responsibility to manage that forest. Some activities are legally obligatory and some are voluntary. Generally, the amount of work involved is positively correlated with the size of the holding. In order to generate revenue, a threshold minimum work input is required. The work can be undertaken by the owners themselves, by hired contractors or by a combination of the two. For logging in the Nordic countries, the self-employed work normally involves motor-manual and mechanised operations (i.e. the use of chainsaws and some kind of mechanised extraction equipment), whilst contractors' operations are fully mechanised (i.e. using harvesters and forwarders). Planting and pre-commercial thinning (PCT) are conducted in the same way, whether by self-employed owners or by contractors. Planting is a manual operation and PCT is conducted motor-manually.

Firewood processing is normally prompted by the possession of a residence that has a firewood-requiring heating system. The firewood needed is often processed by the consumer, but it is also possible to purchase processed firewood. The processing is conducted manually or motor-manually. Work in both self-employed forest work and firewood processing is generally characterised by highly repetitive operations with simple, but potentially dangerous, machines or tools.

Little attention has been paid to self-employment in forestry, even though such work is common across Europe (e.g. Lidestav, 1998; Karppinen *et al.*, 2004; Medved, 2004; Pivoriunas & Lazdinis, 2004). Studies of self-employment have generally focused on measures of activity on holdings (e.g. amounts of timber supplied to industry) rather than the people involved, apparently because a prime concern has been to ensure that sufficient raw material supplies are maintained to meet industrial needs. Accordingly, it is not surprising that studies that do address the self-employed forest owner generally focus on logging. Compared to family forest owners who hire contractors for logging, owners who are self-employed in logging are younger, more likely to be farmers and more likely to be resident on their forest holdings in both Sweden (Törnqvist, 1992) and Finland (Hämäläinen & Kettunen, 2001). However, the cited studies considered only a limited group of family forest owners within their respective study areas and thus their results may have limited applicability to self-employed people in family forestry and their activities in general.

From 1975 to 2002, the work performed by self-employed people in family forestry accounted for half of the total number of hours worked in Swedish forestry (National Board of Forestry, 2004). However, both the number of hours they worked (Fig. 1) and the amount of work they undertook decreased during this period (National Board of Forestry, 1994; 2004). Possible reasons for this decline include a genuine reduction in activity and increased efficiency of the equipment used. Although levels are decreasing, a considerable amount of work is still performed. In 2002, 6.1 million m³ wood was logged, 31,000 ha was planted and 114,500 ha was pre-commercially thinned in self-employed family forestry (National Board of Forestry, 2004). In the 1990s, self-employed forest work was undertaken on almost 88% of the family forest holdings (Danielsson, 1998).

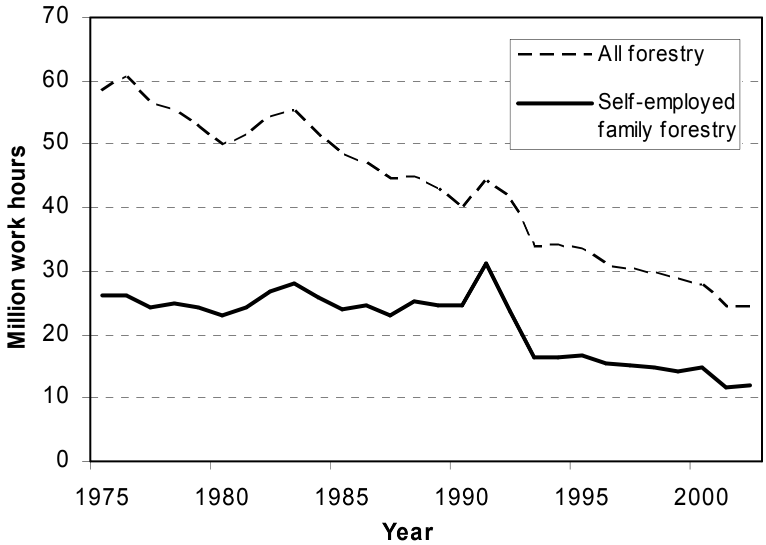

Figure 1. Work time in Swedish forestry, 1975-2002 (National Board of Forestry, 1994; 2004).

Contemporary data on firewood processing in the Nordic countries are scarce, apart from estimates of wood consumption (Tuomi, 2003; National Board of Forestry, 2005). However, the estimations indicate that the activity is common, as has been found in other parts of the world. For example, Driscoll et al. (2000) found that 84% of the timber used for firewood in Australia is obtained from private property and that approximately half of the firewood burned in households is collected by the residents. Firewood gathering by residents is also common in the U.S.A (Skog & Watterson, 1984; Force, 1989; Christiansen *et al.*, 1993).

Residential firewood

Firewood is mankind's oldest energy source and is still extensively used around the globe (Anon., 2005), even in technologically advanced and highly energy consuming countries (Warsco, 1994; Röser *et al.*, 2003; Jouhiaho, 2004). Firewood production has seldom been included in studies on family forestry, but is believed to be an important driver of self-employment in forestry. Furthermore, it has characteristics in common with traditional self-employed forestry and is the end-point of one of many processing chains that is initiated with the harvesting and extraction of trees from the forest (c.f. Fig. 3). In this thesis firewood is defined as solid wood, mainly from the tree trunk. Firewood processing is defined as the processes of transforming logs into burnable pieces, including the storage of firewood and transportation to the burning facility. Harvesting trees and extracting the logs from the forest are here regarded as forest operations (cf. Fig. 3).

After the energy crisis in the 1970s, the amount of firewood used was subject to extensive monitoring (e.g. Lipfert & Dungan, 1983; Skog & Watterson, 1984), but it attracted less attention in the 1990s (Arnold, Köhlin & Persson, 2006). In the new millennium, interest in firewood has revived; its use is likely to increase, due to rising costs of alternative sources of energy for heating (e.g. electricity and petroleum products) and there is increasing interest in the use of all sustainable and environmentally friendly heating systems. In Finland, for example, 15,000 households planned to start using firewood and 200,000 households planned to increase their firewood consumption during 2002-2003 (Tuomi, 2003). Finland's annual firewood consumption of 6.1 million m^3 is very similar to Sweden's annual consumption of 6 million m^3. In Sweden, the consumption corresponds to 8.9% of the timber annually harvested (National Board of Forestry, 2005). In Australia, more than 4.5 million tonnes of firewood is burned for domestic use every year and about 23% of all households use firewood (Driscoll, Milkovits & Freudenberger, 2000). The importance of firewood is reflected in estimates that it supplies 21.6% of the energy used to heat detached houses in Sweden (Statistics Sweden, 2003) and 1.5% of the total energy consumed in the country (National Board of Forestry, 2005). Although the amounts of firewood consumed are relatively high, discrepancies in official statistics imply that it has been generally underestimated. For example, there is a deficit in the balance between self-employed logging volumes and firewood consumption in Sweden of 0.5 million m^3 (National Board of Forestry, 2005), even though the logging volume are supposed to also include timber sales to forest industries.

Mechanisation

In the processing industries of industrialised parts of the world, most work activities have been mechanised or automated, and labour-intensive work methods have mainly been retained in situations where labour costs and/or investment capacities are relatively low. The effects of these factors can be observed even within industrialised countries, especially in self-sufficiency sectors, one of which (to a certain extent) is forestry in Sweden. Most industrial forestry activities, as practiced by large forest companies and entrepreneurs for harvesting and processing timber and pulp-wood, have been heavily mechanised. Nevertheless, motor-manual tree felling is still common in Sweden and in most other parts of the world. Even in areas with a high level of mechanised forest operations, chainsaws are used in places where conditions are unsuitable for mechanised work, for instance places where the terrain is steep and/or trees with very large tree diameters are being felled (Silversides & Sundberg, 1989; Nordfjell *et al.*, 2004). Furthermore, motor-manual operations have clear advantages over highly mechanised operations in situations where the capital investment potential is low (Silversides & Sundberg, 1989; Nordfjell, *et al.*, 2004), which probably explains the slow pace of mechanisation in self-employed family forestry. Generally, small-scale approaches are more suitable in this context, and the owners tend to invest time rather than money in their forest operations. These considerations may also apply to entrepreneurs in countries with low labour costs, as an alternative to investing in highly mechanized forest equipment (Sundquist, 1983; Lindroos & Gallis, 2003).

Despite its lower level of mechanisation, small-scale forest equipment has developed simultaneously with its large-scale equivalents through adapting and implementing new technical solutions for small-scale applications. Large sales numbers imply that there is strong interest in small-scale equipment among the family forest owners and that design and development efforts of the manufacturers of small-scale equipment have been successful. In Sweden year 1992, the aggregate sales value of equipment for self-employed activities was estimated to be greater than the aggregate sales value of harvesters and forwarders (Herlitz, 1993). During the period 1980-1992, mean annual sales of new tractor-drawn timber trailers amounted to 1,200 units in Sweden (Trulson, 1987; Herlitz, 1993), and between 1987 and 1992 mean annual sales of new chainsaws and brushsaws amounted to 46,100 and 18,400 units, respectively (Trulson, 1987; Herlitz, 1993). A case study in northern Sweden found that 14% of family forestry's turnover from cutting was reinvested in equipment (Holmgren, Lidestav & Nyquist, 2005).

The work of harvesting, extracting and processing of firewood was subject to studies already in previous centuries (Micklitz, 1860; Micklitz & Micklitz, 1860; Ekman, 1908; Anon., 1924; Aro, 1937; Sundberg, 1941). In that context, the separate branch of small-scale forest technology dispersed from large-scale forestry quite recently and was frequently studied from the beginning of the 1980s to the mid-1990s. Firewood processing was also studied during this period, probably partly due to the general revival of interest in self-employment and self-sufficiency, and partly due to the energy crisis in the 1970s. The research provided knowledge about the methodology, productivity and competitiveness of small-scale forest and firewood technology with various types of equipment (e.g. Folkema, 1983; Swartström, 1986; Etelätalo, 1989; Granqvist, 1993; Johansson, 1994; Nordfjell, 1994; Gullberg, 1995). In the last decade there has been less scientific focus on small-scale forest technology, even though some studies have been conducted (Lindroos, 2004; Horvat & Susnjar, 2005; Shrestha, Rummer & Dubois, 2005). Recent studies on firewood processing have mainly focused on productivity and economic aspects of commercial firewood production (e.g. Borschmann & Poynter, 2003; Jouhiaho, 2004).

Economic aspects

A forest owner is the producer and holder of raw material - the trees. To generate economic benefits, a certain amount of labour is required to transform the grown biomass to merchantable products. The income from self-employed forestry includes both compensation for the owner's labour (i.e. avoided costs of hiring contractors) and the revenue from products sold. If a product instead is used to satisfy domestic needs an expense is avoided (Fig.2). Self-employed logging for commercial returns occurs in Sweden, but constitutes a very small proportion of the performed work. The same is also true for commercial production of firewood, since firewood is principally processed to satisfy domestic heating needs, as previously mentioned. Self-employed logging is generally less cost-effective than hiring fully mechanised alternatives (Gullberg, 1991; Dahlin & Eriksson, 1992). Self-employment in silvicultural activities such as planting and pre-commercial thinning (PCT), in contrast, is more competitive (Dahlin & Eriksson, 1992) since they are performed in the same way by both contractors and self-employed forest owners, and the activities generally do not generate any merchantable products. Firewood processing provides firewood for heating, and thus avoids the cost of more expensive heating alternatives. Consequently, the activity has additional economic benefit besides avoiding the need to hire labour and to sell products (Fig. 2). The ways in which self-employed work affects the owner's overall finances depends on their work alternatives and the equipment used. If the owner has no better-paid options, self-employment can be profitable even at low work compensation levels. However, if the owner values his or her labour highly, greater efficiency will be required. A common way to increase efficiency is to increase the level of mechanisation of the equipment used and thus increase productivity. However, high productivity is also often associated with high purchase costs, so the volume of income-generating products per annum needs to be sufficient to warrant its use rather than the use of less productive but less expensive equipment (Gullberg, 1991). In cases of self-sufficiency uses, however, the constraints imposed by fixed and often low production volumes restrain investment frames in order to minimize costs (Gullberg, 1991).

In cases where there is little or no compensation requirement, the owner's available time is the main factor affecting efficiency requirements. The less time that is available, the more efficient the equipment needs to be for a given amount of work (e.g. to thin 2 ha or process 20 m^3 of firewood). Efficiency is, generally, positively correlated to the level of investment and investment intervals depend on the equipment's lifespan. Factors other than efficiency also influence investments in equipment. The tax system, to some extent, promotes investment in equipment (Holmgren, Lidestav & Nyquist, 2005) and psycho-sociological factors (e.g. advertising and group pressures) are also probably involved in the decision process. Investments can serve as indicators of future self-employed activities, because the purchase of new equipment indicates an intention to use it in subsequent years.

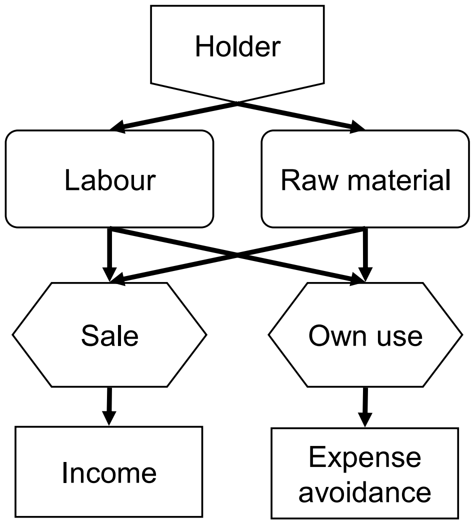

Figure 2. Possible ways for the holder of labour and/or raw materials to generate economic benefits.

Expected trends and motives

Based on recent declines in work time (Fig.1) and timber deliveries to industries from the self-employed family forestry and the idea that human rationality is restricted to economic calculations, a general opinion in the forest sector is that self-employed family forestry is diminishing (Sennblad, 1987; Tham, 1990; Ager, 1995). As previously mentioned, however, family forest owners have more than economic objectives. Ager (1995) and Törnqvist (1995) argued that motives for undertaking self-employed forestry work include factors such as a tradition of self-employment and satisfaction derived from control of the holding and the physical work, as well as its potential profitability. For children of forest owners it has been argued that helping with forest work on the family's property not only provides experience, but also makes them more likely to inherit the property than non-participating siblings (Lidestav & Nordfjell, 2005). A combination of motives has also been argued for firewood processing, two of the main ones being to obtain a cheap source of heating energy and physical exercise (Isachsen, 1984). However, economic rationales have been found to be based more on perceptions than on pure analyses of costs and benefits (Force, 1985).

Safety

Forest work has been identified as an occupation with high risks of work-related injuries. Relevant research has mainly focused on professional workers in industrial, large-scale forestry (Östberg, 1980; Slappendel *et al.*, 1993; Driscoll *et al.*, 1995; Axelsson, 1998; Lilley *et al.*, 2002), frequently on tasks involving the use of chainsaws and other logging machinery. Persons self-employed in family forestry and small-scale firewood processing generally spend much less time on these activities annually than professional loggers (Wilhelmson *et al.*, 2005). They are therefore likely to be less experienced and knowledgeable about the risk factors involved. Experience and knowledge has been argued to play important roles in accident avoidance in both forest-related safety research focussed on individuals (Doyle & Conroy, 1989) and in more general organisational safety research (e.g. Reason, 1995).

Accidents have decreased considerably in industrial forestry as a result of mechanisation (Laflamme & Cloutier, 1988; Axelsson, 1998; Bell, 2002), while there have been smaller changes in both mechanisation and accident frequencies in Swedish self-employed family forestry. In fact, the accident rates in self-employed family forestry are at similar levels to those of professional chainsaw operators in the 1970s, before the widespread mechanisation of industrial forestry in Sweden (Axelsson, 1998). Fatal accidents in Swedish self-employed family forestry constitute 7% of reported fatal work accidents (Burström *et al.*, 2005) and account on average for 10 lethal accidents per year (Axelsson, 1998; Thelin, 2002).

The chainsaw is the most commonly used type of equipment in small-scale logging, but it causes lethal injuries less frequently than falling trees (Thelin, 2002). The development of safety features for chainsaws and personal protection gear has reduced accident rates considerably (Klen & Väyrynen, 1984; Axelsson, 1998). However, a full range of personal protection gear is not always used by self-employed forest owners (Doyle & Conroy, 1989; Liss & Sennblad, 1989; Neely & Wilhelmson, 2006) and it is not designed to protect the user from the energies released by falling trees. In other words, skills in safe work techniques are also required for the prevention of accidents.

A falling tree has large kinetic energies, posing great hazards if not handled properly. The work involved in felling trees is thus the most dangerous work in forestry, and causes the largest proportions of lethal accidents in both large-scale and small-scale forest operations (National Board of Forestry, 2000; Thelin, 2002; National Board of Forestry, 2006). A large proportion of non-lethal accidents is also associated with tree felling (Holman, Olszewski & Maier, 1987; Liss & Sennblad, 1989; Lefort Jr. *et al.*, 2003; Neely & Wilhelmson, 2006). In motor-manual operations, unpredictable direction in which the tree fall is a main cause of severe and fatal accidents (Gustafsson, Lagerlöf & Pettersson, 1970; Neely & Wilhelmson, 2006). Even if an unpredicted falling direction not directly causes an accident, it may result in lodged trees. The work required to bring such trees to the ground both decreases productivity and is hazardous (Koroleff, 1947; ILO, 1998). Pushing on the trunk by hand can sometimes be sufficient to force a tree to fall in a desired direction, but the action can result in back strain injuries (Härkönen, 1978), especially if the work load is high (e.g. if the tree is large or has been poorly cut). To prevent strain injuries and trees falling in undesirable directions, various tools have been developed for safe, controlled felling. Tools such as forestry jacks, felling levers and wedges all augment human force inputs, and thus provide additional felling torque in attempts to make the tree fall. Felling tools are believed to be commonly used, although there is little reliable information to support this assertion. Felling levers were commonly used in Sweden, at least in the beginning of the 1970s, but their use varied regionally amongst self-employed forest workers (Blom, Johansson & Öhlund, 1973; Friberg, Delin & Ottosson, 1974; Gårdh, 1974).

Little is known about the working conditions and accident rates of individuals primarily involved in small-scale firewood processing. In Sweden, the numbers of such accidents have been surveyed and they have been estimated to account for a wide range – from 11% (Neely & Wilhelmson, 2006) to 100% (Wilhelmson*, et al.*, 2005) – of the total number of accidents in self-employed forestry. Accidents that occur during firewood processing often result in severe hand injuries (Kristiansen & Seligson, 1981; Hellstrand, 1989; Larsson, 1990; Wilhelmson*, et al.*, 2005). Different kinds of equipment have different mechanisms and thus involve different sort of risks. However, knowledge is limited about the proportions of different types of equipment used and, consequently, about the distribution of risk factors. Furthermore, data on the prevalence of prescribed safeguards and compliance to safety regulations such as those related to working alone are scarce.

Objectives

The overall objective of this thesis was to examine efficiency and safety in self-employed family forestry, including firewood production. For this purpose, four studies were conducted on key identified aspects.

The objective of study I was to investigate the extent of engagement in self-employed forestry work and the extent of investment in equipment in order to analyse the present state of self-employment and to forecast future trends.

Since manual tree felling causes the majority of lethal accidents, the objective of study II was to develop and evaluate a realistic and convenient method to study felling tools' capacity in terms of the potential torque they can generate in the work to bring down trees after performed cutting.

Large proportions of non-lethal accidents in self-employed family forestry occur during firewood production. The objective in study III was, therefore, to increase knowledge on the work and the characteristics and rates of accidents in small-scale firewood production in order to facilitate the development of preventative measures.

Mechanisation of large-scale forestry has increased efficiency and decreased accident rates in the industry. Analogously, the mechanisation of firewood processing could have similar benefits. Following this rationale, the objective in study IV was to analyse the potential efficiency gains that increased mechanisation could yield in small-scale firewood production.

Contextual framework

A number of important activities involved in self-employed family forestry are addressed in this thesis. Figure 3 illustrates the activities' interrelations and indicates those examined in each of the studies. Study I focused on the self-employed work involved in family forestry in a broad context, with quantification of persons active in the silvicultural activities planting and pre-commercial thinning, and the motor-manual logging activities cutting and extraction. The efficiency of tools for tree felling was considered in II. Much of the felled wood is ultimately used as firewood, and the work involved in the production of this material was addressed in III (in terms of its extent and associated accidents) and IV (its efficiency).

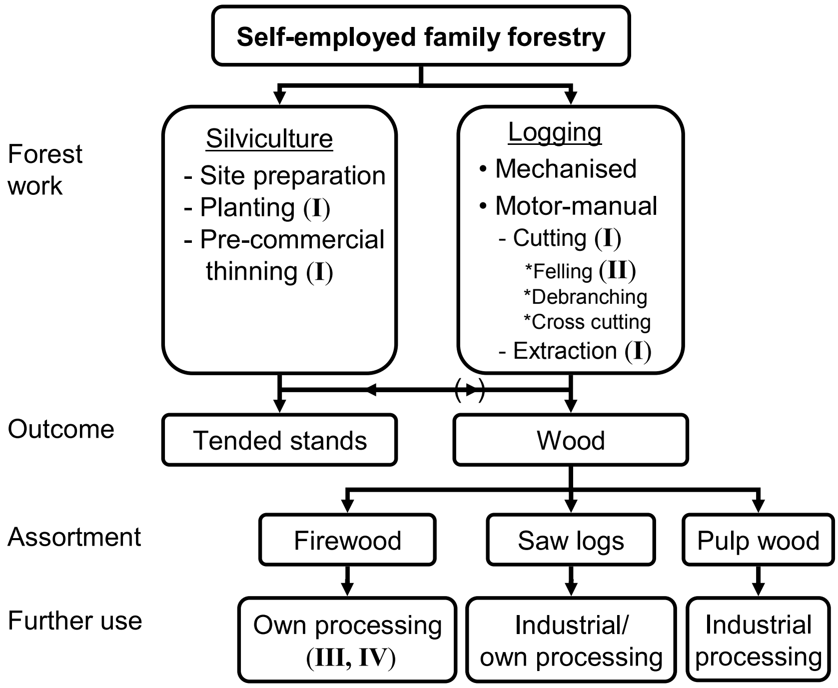

Figure 3. Contextual framework for the work activities studied in the research underlying this thesis. Roman numerals indicate papers that deal with the respective activities.

An accident is the result of a long chain of decisions and actions (e.g. Reason, 1995). Analogously, the outcome of a production process can be seen as the result of a chain of similar factors. To visualise the chain(s) involved, and the links examined in I-IV, the model presented in figure 4 was developed. Both human and technological factors (and interactions between them) that might lead to, or help avoid, an accident are involved in the work process. Personal factors affect the choice of equipment and how it is operated. The interaction between operator and equipment determines production rates. Simultaneously, the production involves a certain exposure to risks, which if managed inappropriately can result in accidents. The papers on which this thesis is based focus mainly on the technology and interaction factors. Paper I considers the equipment and number of active persons involved, which are key determinants of work time. Paper II concerns equipment and work methods. Personal properties, equipment, work time, safety features, exposure and accidents are assessed in III. Paper IV deals with equipment, work methods, production, produce and to some extent behaviour and safety features.

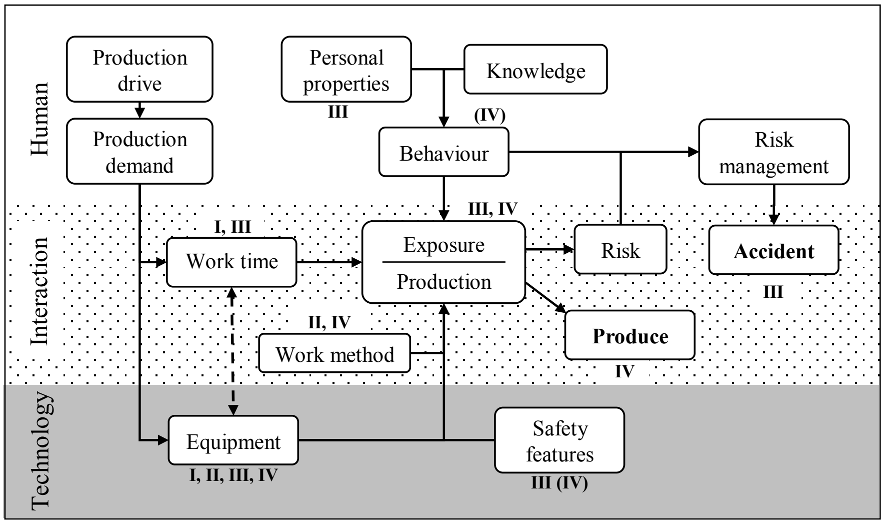

Figure 4. Contextual framework for the work and accident factors considered in the thesis. Roman numerals indicate papers concerned with the respective factors.

Material and methods

Paper I

Survey of private forest owners

In 1997, a questionnaire was sent to a random sample of Sweden's family forestry owners aged between 18 and 80 years who owned at least 5 ha of forest land. They were stratified into three holding size classes (5-49, 50-399 and >399 ha) and six ownership classes (single male owner; single female owner; multiple male owners only; multiple female owners only; male and female owners, male respondent chosen; male and female owners, female respondent chosen). Simple random sampling was conducted within each of these 18 strata. In total 2,500 forestry owners were selected and the reply rate was 58%. No significant differences in age or holding size were found between respondents and non-respondents. The questionnaire is described in Lidestav and Nordfjell (2002).

In the survey, respondents were asked whether self-employed forest work was normally conducted by the respondent or by family members and co-owners. Only the respondent's (i.e. the forest owners') self-employment was considered in this study. Self-employed work was not limited in level or amount. Hence, contractors could be hired for most of the forest work and the forestry owner would still be considered self-employed. Furthermore, the focus was not on a particular period of time, since intervals between forestry work can be long. However, responses most likely reflect the situation in the 1990s. Based on the definitions, all family forestry owners likely to own forestry equipment were targeted.

The results for the various strata were conjugated to population totals for statistical inferences, taking into account the different sampling fractions across the strata. For all estimated population parameters, 95% confidence intervals were calculated. Data were analysed to identify possible significant differences between the sub-populations 'self-employed' and 'not self-employed' family forest owners at the level of the characteristics. The critical significance level was set at 5%.

Interviews with manufacturers and importers

Full statistics pertaining to sales of equipment suitable for self-employed forestry in the Swedish market (excluding second-hand equipment) were gathered for the year 2002. Names of manufacturers and importers were identified throughout the data collection period from equipment catalogues and advertisements in trade journals and on the internet. Sales representatives of the companies identified were interviewed by telephone or in person, between February 2003 and September 2004. Equipment for cutting, extraction, pre-commercial thinning (PCT), mechanical site preparation and firewood procurement was included, separated into 17 categories. Equipment that could not be classified as machinery or with a mean unit price of less than €170 was not included. The data collected included the number of new sales and the aggregate retail sales value for the Swedish market. Among the included categories, seven were considered to be exclusively used by self-employed family forest owners and for forestry. Estimating the proportions of the sales destined for forest work by self-employed family forest owners was, therefore, difficult. In total, 101 companies were contacted, of which three importers refused to participate. Sales statistics were considered to be a full survey of the entire population, and hence statistical analysis was not relevant. No estimates were made of the non-respondents' sales because it was considered more valuable to have a precise minimum level of sales than an estimated total level.

Paper II

The method for assessing the capacity of felling tools to tip trees over was developed using real, unfrozen Scots pine trees (*Pinus sylvestris* L.) in two adjacent forest stands. Trees of two diameters, 20 cm and 35 cm on bark at stump height, were selected to provide indications of the effects of the trees' diameters on the forces and torques generated by the tools. Trees were cut by chainsaw 1.65 m above the planned felling cut, to exclude bias from the trees' crown shape and wind.

Each test tree was cut in a standardised way, in which the felling cut and the bottom of the notch were horizontal and level with each other. Notches and hinges of the desired depth and thickness, respectively, were created using a caliper-shaped tool, which indicated the correct dimensions. The remaining part of tree above the felling cut is referred to hereafter as the trial stem, and the part underneath it as the stump (II, Fig.6). The trial stems were each attached to a neighbouring tree by an anchoring line, placed 1.6 m above the felling cut, and the felling direction was 180° to the anchoring direction (II, Fig.6). The anchoring line consisted of slings placed around the stems and tightened by ratchet straps. Between the sling and strap, a Bofors 10 kN load cell (model KRG4) was placed to record forces in the anchoring line. Surplus torque (i.e. the torque exceeding that required to overcome resistance and thus cause stem movements) was used as the response variable in the data analysis. Trial stem movements were manually recorded using inclinometers attached to the trial stems.

The studied tools were one model, respectively, of forestry jack, felling lever, and wedge. For each tool, standardized forces were applied consecutively without releasing the tension of the anchor line tension. All tools were applied 180° to the felling direction. Within each of the two stump diameter classes, 21 trees were randomly chosen, and seven from each class were randomly chosen for each of the tool orders JLW, LWJ and WJL, where J, L and W denote forestry jack, felling lever and wedge, respectively. The applied forces on each tool were the same for both diameter classes and all tool orders. This intermix design enabled each tool to be studied as first, second and third treatments an equal number of times. The method used to analyze effects of treatments for each tool was Analysis of Variance (ANOVA), and the general linear model (GLM) was used to analyse the ANOVA models (Minitab 14, Minitab Ltd.). Relations between input torques after compensating for lean were analyzed with linear regression within trees. Differences between regression equations were analyzed with F-tests. Results of statistical analyses were considered significant if $p \leq 0.05$.

Paper III

The study targeted the Umeå region, consisting of a medium sized Swedish city (Umeå) surrounded by five municipalities (Bjurholm, Nordmaling, Robertsfors, Vindeln and Vännäs). In each of these rural municipalities there is a commercial and administrative centre, but they are mainly characterised by small, scattered villages and forested land. The total number of inhabitants in the region was 142 000, 71 000 of whom resided in the city of Umeå, and the land area was 9372 km^2 (Anon., 2006). The region was considered to represent typical Swedish conditions. Two surveys were conducted in the area, one focussing on firewood production and one focussing on recorded accidents.

The region's chimney sweepers' register of households with firewood-based heating systems was consulted and used as a sample frame. Sweeping was compulsory by law during the study period and intervals were decided by burning intensity in combination with wood stove type. Simple random sampling was used for selecting 1500 households, to which a mailed questionnaire was sent in April 2006 and a reply frequency of 61% was obtained. There was no significant difference between respondents and the non-respondents with respect to either municipality or stove type.

Data on personal injuries from 1 Jan 1996 to 31 Dec 2001 were collected from an injury database, maintained by the Umeå Accident Analysis Group at the

University Hospital in Umeå. Through a database search and review of medical journals, injuries that could have occurred during self-employed forestry work were identified. In 2002 a questionnaire were sent to the 485 persons and responses were received from 385 people (80%), 225 out of whom confirmed that the accident had happened during the target activity. Respondents were not significantly different from non-respondents with respect to gender, age or the seriousness of the accident. Some of the survey results have previously been reported (Wilhelmson*, et al.*, 2005). In this article, however, a more thorough analysis of firewood production accidents is presented, based on the 116 accidents that happened during firewood production.

Categorical data were analyzed with χ^2- tests, with Yates correction for continuity when necessary. For ratio scale data, means and standard deviations (SD) were calculated and comparisons between groups were made with T-tests. The critical significance level was set to 5%.

Paper IV

Differences in firewood productivity when using identical main machine components but with different levels of mechanisation were analyzed in an experimental study. Two systems were studied, one of which included two machines while the other included just one machine. Wood of two classes was processed in tests with each machine, resulting in six treatments. In all of the tests with the two-machine system the wood was processed sequentially by the two machines (cutter then splitter) in a single day. Each day was divided into three 90-minute and an individual operator worked on all treatments over a two-day period. In total, 12 operators were randomly assigned to treatment orders and work days.

The first system consisted of a blade saw and a hydraulic wedge splitter, hereafter called *cutter* and *splitter*. The whole system is called system *cut-split*, with which the two steps in the processing were conducted separately in both time and space. The second system consisted of a firewood processor, hereafter called *processor* or as a system, system *proc*, with a blade saw and a hydraulic wedge splitter. With the processor, the two processing steps were separated in time but integrated spatially. A chunk that was cut of a log fell into the machine’s splitting department and the operator actuated the splitting and then waited until it had been split before starting the next cutting. Manual loading of chunks to be split was thus avoided.

The firewood processing systems were studied during November and December 2005, in a building with roofing, but no walls. The material used in the study consisted of 2,199 birch (*Betula* sp.) logs with a total volume of 91.9 m³ solid wood on bark. Prior to the study, the logs were manually measured, enumerated and sorted into three groups according to their root diameter on bark (7.0-12.9 cm, 13.0-17.9 cm and 18.0-30 cm). Logs in the smallest and largest root diameter group were put together in a ratio of 5:1 to constitute wood class 2, while the logs in the medium root diameter group constituted wood class 1. Due to the climate, logs were frozen during the study

Twelve subjects were selected to compose a homogenous group of males aged 60-79 years with thorough experience of processing firewood with circular saw cutters and hydraulic splitters. Prior to each work shift, subjects were given instructions regarding safety, standardised work routines and asked to work at their own pace. Subjects' heart rates were recorded with cordless heart rate monitors, and the subjects were told not to discuss the study with each other. The length of the billets produced was set to 30 cm and all wood was to be split. During work shifts, subjects were observed by a researcher who corrected unsafe behaviour, violations to standardised work routines and helped to correct machine malfunctions.

Continuous time studies were performed using Husky FS3 hand-held computers running Siwork 3 version 1.1 software. Cutter and processor work elements were loading, machine work, miscellaneous and delays. For the splitter, the work elements were identical except for the absence of loading. The work elements did not overlap and thus, no priority order was assigned. For all work periods, deviations from normal work procedure were counted, and divided into the elements re-cuts, re-splits, external interruption and internal interruption.

Directly after each work shift the subjects were individually interviewed about their perceived level of exertion, efficiency, motivation, risks and interruptions during the normal work. Perceptions were reported on a Borg CR100 scale with instructions adapted from Borg (1998). Borg's Category-Rate scales are suitable for measuring the intensity of most types of experiences (Borg, 1998). The interviews also concerned causes of interruptions, desired changes in the work, perceived risks and whether the subject would like to work in a similar fashion at home.

The method used to analyze effects of treatments was Analysis of Variance (ANOVA), and the general linear model (GLM) was used to analyse the ANOVA models (Minitab 14, Mintab Ltd.). Due to operators' significant contributions in the study, pairwise differences were analyzed with Wilcoxon's Signed Rank test (WSR) (SPSS 12.0, SPSS Inc.). When there were no differences between operators, pairwise differences were analysed with Tukey's HSD test in cases of homogeneous variances (Laverne statistic) and otherwise with Dunnet's C test (SPSS 12.0, SPSS Inc.). Analyses of Pearson's correlation coefficient were used to assess relationships between the variables, which were established through regression analysis. Results of statistical analyses were considered significant if $p \leq 0.05$ and to indicate tendencies if $0.05 < p \leq 0.10$.

Results

Paper I

In total, two thirds of the forest owners were self-employed (I, Table 3), and this class included significantly higher ($p<0.01$) proportions of males, residents on the holding, farmers and members of forest owner associations than the forest owners who were not self-employed. The group of forest owners who did not conduct self-employed forestry contained a significantly higher ($p<0.01$) proportion of co-owners. The most significantly differentiating characteristic was gender, since the proportion of women was much higher among 'not self-employed' forest owners than the total population. Self-employed forest owners were significantly ($p<0.05$) younger (52.3±0.9 years, mean±95% confidence interval) than those who were not self-employed (54.0±1.3 years). The two most commonly undertaken activities were planting and pre-commercial thinning (PCT), which half of the total number of forest owners performed (I, Table 3). For all self-employed activities except planting, a smaller proportion of women participated than the proportion in the entire population of self-employed forest owners. Forest owners who performed cutting and extraction were more likely to be resident on the holding and to be farmers than forest owners undertaking planting and PCT.

During 2002, the sales value of new equipment suitable for self-employed forestry was €67.0 M, and 83,901 units were sold (I, Table 4). Almost three times as many chainsaws were sold as the second most frequently sold type of equipment, brushsaws. Chainsaws also had the highest sales value, closely followed by grapple loader trailers. Firewood splitters and firewood processors were supplied by the highest number of manufacturers and importers, followed by grapple loader trailers. Firewood splitters were also available in the greatest range of models, followed by grapple loader trailers. In terms of the mean number of models offered per company, chainsaws with engine displacement over 40 cm^3 were the most diverse (8.2), followed by grapple loader trailers (4.6) and brushsaws (4.5).

In 2002, the sales value of seven comparable equipment categories was 88% of that in 1992 (Herlitz 1993) (I, Fig. 2A). More all terrain vehicle trailers and grapple loader trailers were sold in 2002 than in 1992 (I, Fig. 3B-C), while sales of snowmobile sleighs, wire cranes, small forwarders and mini forwarders decreased (I, Fig. 3B-D). There were notable changes in chainsaw and brushsaw sales between 1992 and 2002; their sales value decreased but the number of units sold remained the same, indicating that the mean unit price decreased (I, Fig. 2B). Although consumption of firewood has been stable since 1990 (National Board of Forestry 2004), new sales of firewood splitters were eight times higher in 2002 than in 1986 (Trulson 1987) (I, Fig. 3A).

Paper II

The order in which the tools were applied to trial stems had a significant effect on the recorded surplus torque, so only results from trial stems to which each tool was applied first were further analyzed. For those trial stems, both the tree diameter and the applied force had significant effects on recorded torque for all tools ($p \leq 0.044$). For the lever and wedge there were significant interaction effects between diameter and applied force ($p \leq 0.007$). The individual trees had a significant effect on the recorded surplus torque for all tools ($p=0.000$).

Unsurprisingly, for all tools, the ratio between surplus torque and input torque (after compensating for the effect of the trial stem's leaning) was lower for trees of the larger diameter class than for the smaller trees (Fig. 5 and II, Fig. 7). The ratios for the forestry jack indicate that its efficiency increased substantially as the applied force was increased in tests with trees in the 35 cm diameter class, but this variable had relatively little effect in tests with trees in the 20 cm class.

Within trees, correlations between input torque and recorded surplus torque were linear (Fig. 5). For the tree jack, the regression slopes within the 14 trees in both diameter classes were not significantly different ($p=0.477$) and the intercepts between trees were not significantly different within diameter classes ($p>0.128$). Regression lines for individual trees for the other tools differed both between trees and between diameter classes (Fig. 5). The order of individual tree's regression lines were not obviously related to differences in hinge features, wood density or tree age.

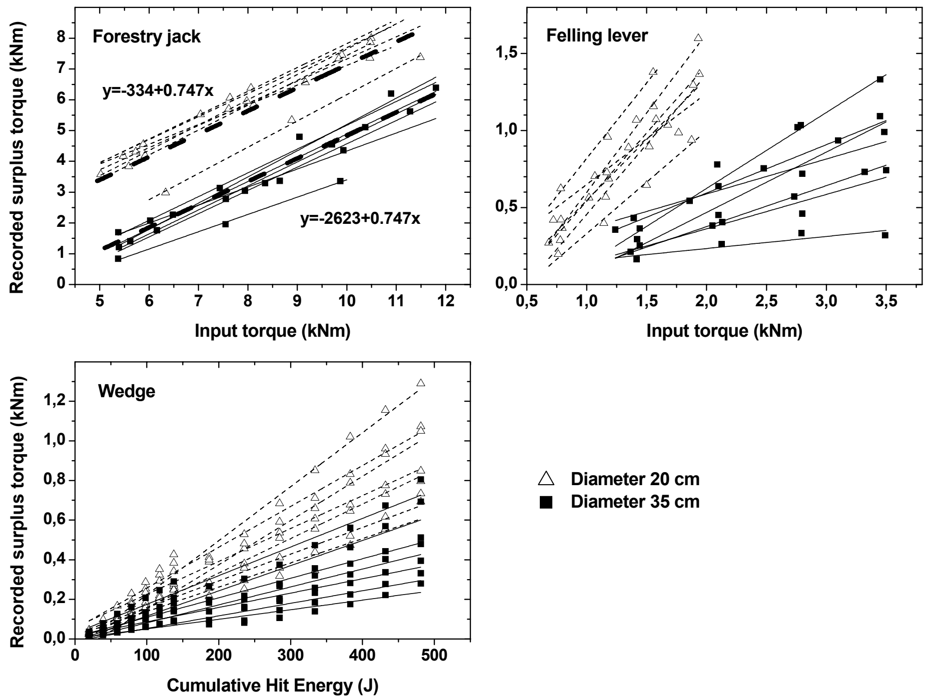

Figure 5. The recorded surplus torque for each of the felling tools as functions of input torque or cumulative hit energy. The regressions are based on three observations per tree for the forestry jack, four for the felling lever and 14 for the wedge. For the forestry jack, the common regression line within diameter class is plotted in bold. For other tools, no common regression occurred. Note the differences in the scales of the x- and y-axes.

Paper III

Reported mean work time was 95.8 h (SD 89.6 h) per household and 54.6 h (SD 59.9 h) per person. Most persons (44.1%) were found in the age classes "50-59" and "60-69" years and these age classes also accounted for most work time (53.2%) (Fig. 6). Men constituted 70.8% of the active persons and performed the work done in 84.7% of the working hours. Men spent on average more than twice as much time on the work compared to women. The mean age for all active persons was 49.0 years (SD 18.3). Men spent 58.8% of their time on cutting, splitting and processing and 41.2% on other work activities (III, Table 2) while women spent 60.4% of their time on stacking and transport.

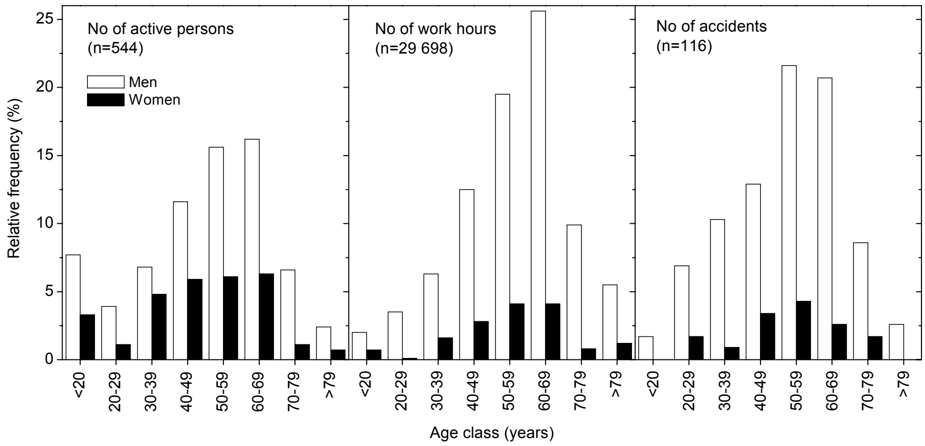

Figure 6. Relative frequencies of firewood processing persons, work time and accidents by gender and age class.

Most of the work time was spent in the use of wedge splitters (III, Table 3 and Fig. 3). Work with the four equipment categories "Chain saw", "Circular saw", "Wedge splitter" and "Processor" collectively accounted for 85.5% of the work time. Of the equipment used, circular saws had the highest mean age (21.6 years) and accounted, together with screw splitters, for the highest proportion of machines older than 11 years (predating 1995), in terms of both numbers (>70%) and work hours (>61%) (III, Table 3).

The majority of accidents occurred to men (85%) (Fig. 6) and with respect to age, most accidents (26%) occurred to people in the age class 50-59 years. The mean age of injured persons was 52.8 years (SD 15.8). Splitting was the activity that was being performed when most (54.3%) of the accidents occurred (III, Fig. 3). Cutting, splitting and processing work was in progress when 93.1% of all accidents occurred. Wedge splitter was the type of equipment that was most frequently being used at the time of injury, (39.4% of the accidents), and consequently the most common type of accident was crushing during wedge splitting (34.5%) (III, Fig. 3 and Table 4).

Most (71.6%) injuries occurred to upper extremities (fingers, hand, wrist and under arm). Injuries to fingers alone accounted for 57.8% of the injuries. The most common injuries were cuts (40.5%) and fractures (20.7%). Fifteen persons (12.9%) had amputations. Persistent symptoms were reported by 51.3% of all the injured persons. As a consequence of their accident, 46.6% reported that they changed their work procedures or worked more cautiously. Eight persons (6.9%) stopped producing firewood.

Less than half (43.1%) of the accidents happened when the injured person was not working alone (III, Table 5). During work with processors and wedge splitters, 72.7% and 51.2%, respectively, of the accidents happened when the injured person was not working alone (III, Table 5) and the resulting injuries were all crushing injuries.

Within the Umeå region, the total annual work time spent on firewood processing in family forestry was estimated to be 378 000 h, giving an accident rate of 51 accidents per million work hours (III, Table 6). Splitting was associated with a far higher rate of accidents (123 per million work hours) than any other activity (III, Table 6), and the rates for the activities stacking and transport were 10 times lower. Among the equipment types, the accident rates were highest for wedge splitters and axes, and lowest for processors.

Expected accident frequencies based on total work time did not significantly differ from frequencies of reported accidents for either sex or age classes in absolute terms. However, when frequencies of expected accidents were based on the numbers of active persons, there were significant deviations from the frequencies of recorded accidents, both between genders and between age classes. The differences indicate that accidents are more closely related to time spent on the work than to numbers of active persons, as clearly shown in Fig. 6. Based on the amount of time spent working with them, wedge splitters were associated with disproportional high accident rates, while processors were associated with disproportional low rates.

Paper IV

The three main effects system, wood class and operator significantly affected time consumption in the efficiency analysis (truncated ANOVA, $p=0.000$), which not was true for the interaction effect of system and wood class ($p=0.479$). The amounts of time consumed were smaller when logs of the higher mean diameter class were processed, and the patterns and absolute values for all but four of the operators were similar (Fig. 7). When data for those four were removed, the effect of operator was no longer significant (truncated ANOVA, $p=0.596$). In addition, removal of these four operators reduced the mean time consumption per m^3 solid wood by 10.6 – 15.0% and the treatment means differed significantly, not only within operators (IV, Fig. 4), but also between operators (Tukey HSD, $p \leq 0.031$). When all 12 operators were included in the analysis, the relative variance in time consumption between operators, measured as coefficient of variance (CV, %), was highest for wood class 1, irrespective of system (IV, Fig. 3). When the four deviant operators (hereafter called 'slow' operators to distinguish them from the others) were removed, the CV generally decreased considerably and was lowest for wood class 1 (IV, Fig. 3). For both all 12 and the eight other operators, the CV for time consumption was lower for system *cut-split* than for system *proc*.

In general, absolute values differed significantly between the four slow operators and the other eight operators (IV, Table 5). However, in analyses of the within-operator effects of combinations of wood classes and systems or machines, the results for the four slow operators did not markedly deviate from the others.

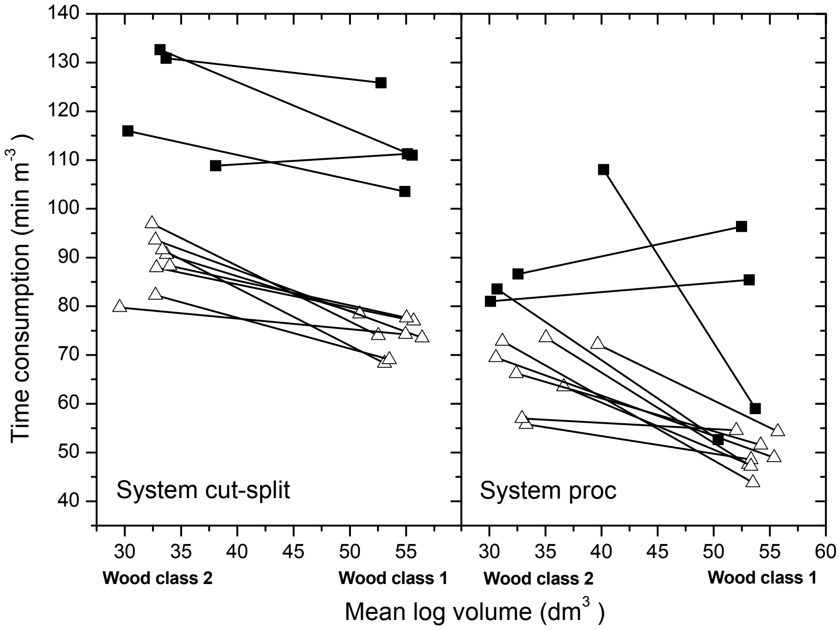

Figure 7. Relationships between time consumption and mean log volume during work shifts. Individual operator's (n=12) values are connected. Four slow operators (see text for definition) are represented by filled squares, while other operators are represented by unfilled triangles.

Work was conducted more efficiently with system *proc* than with system *cut-split* and processing wood of class 2 required more work time than processing wood of class 1 (WSR, $p<0.05$) (IV, Fig. 4). The mean time consumption for all operators per m^3 with system *proc*, expressed as a ratio of the time consumption with system *cut-split* was 0.67 (SD 0.10) and 0.75 (SD 0.13) for processing wood of classes 1 and 2, respectively. The mean time consumption for processing wood of class 1, as a ratio of the time required for wood of class 2, was 0.87 (SD 0.08) and 0.78 (SD 0.18) using systems *cut-split* and *proc*, respectively.

The frequency of deviations from normal work per m^3 firewood produced was significantly affected by wood class and operator (truncated ANOVA, $p<0.011$), and system tended to have an effect ($p=0.058$). Within-operators when processing wood of class 1, there were significantly fewer deviations per m^3 with system *cut-*

split (WSR, $p=0.034$) than with system *proc* (IV, Table 6). No such differences were detected when wood of class 2 was being processed. Within operators, there was a tendency for deviations per m^3 to be more frequent when class 2 wood was being processed, irrespective of system (WSR, $p<0.071$) and the differences were significant when the four slow operators were removed (WSR, $p\leq0.050$). The most common kinds of deviation were external disturbances, of which high proportions were due to chunks and billets jamming the conveyor and malfunctions of the splitting axe.

Deviation frequency was correlated to time consumption (IV, Fig. 5), but when the four slow operators were removed, the effect of deviation frequency diminished (simple regression, system *proc* in wood class 2 $p=0.059$, for all other combinations $p\geq0.687$).

Due to the effects of operator on time consumption, it was important to investigate differences between operators' work in the study. Within operators, the cutter required the least time and the splitter required the most time per m^3, irrespective of wood class (IV, Table 7) (WSR, $p<0.05$). In addition, wood class 2 required significantly (WSR, $p<0.05$) more time per m^3 firewood processed, irrespective of the machine used. Removal of the four slow operators generally decreased mean time consumption by 10.5-17.6%. Within-operators, a larger proportion of the work time was spent on loading for the cutter compared to the processor, irrespective of wood class (Table 8), indicating that the production rate of the former was higher than that of the latter, since the loading conditions for the two machines were identical.

The operators' mean heart rate during the work shifts was 98.0 beats per minute (SD 18.7), corresponding to 35.3% (SD 12.9%) of their heart rate reserve, with significant differences both between machines and between operators (IV, Table 9). Regardless of wood class, operators used more of their heart rate reserve when working with the cutter than when working with the splitter (WSR, $p<0.021$).

Perceptions of the work significantly differed between operators, but there were no significant effects of machine, wood classes or combinations of machines and wood classes on their perceptions (IV, Table 9). Operators reported that their levels of exertion were generally moderate to strong during the work (36.0±14.7 cM) and that they were very satisfied with the efficiency of machines and work methods (50.5±19.0 cM). Operators perceived a strong motivation for the work during the study (52.5 cM±20.1 cM), with motivation being significantly higher during work with the splitter than with the cutter (WSR, $p<0.009$). When the four slow operators were removed, the perceived motivation was significantly higher during work with the processor than during work with the cutter, irrespective of wood class (WSR, $p\leq0.033$). The accident risk was perceived as being very low. The splitter was perceived as the least risky machine, (6.4±5.2 cM) while the cutter and processor were perceived as slightly more risky (9.6±7.3 cM and 9.5±7.8 cM, respectively).

General discussion

Here, matters of general interest for the thesis are discussed. For matters concerning specific papers, the reader is directed to the discussions in the papers.

Generalisation of results

Geographical and demographical representativity

As mentioned in the introduction, self-employed family forestry is common in many regions in the world, especially when firewood production is included. The current thesis has mainly focused on Sweden, but the results are also believed to be applicable elsewhere. The results in I and III are likely to be the most particularly relevant to Sweden, although many similarities could probably be found elsewhere, especially the in other Nordic countries, but also in other industrialised countries in which a substantial proportion of forest is owned by private individuals. The applicability of the results to groups other than family forestry owners and their assistants is limited except for those of III, since its hitherto unpublished part of the survey of firewood production revealed an equally large body of non-forest owning, but firewood-processing people. The characteristics of work and accidents found in III were not obviously forestry related and are therefore probably also valid for firewood-producing people who do not own forest.

Questionnaires

In the use of questionnaires, two main limitations have to be considered. The first is the part of the population that is not included in the sample and the other is the part of the sampled population that does not reply. The first limitation is a function of the sample size, and is related to how likely the results are to mirror the total population. The larger the sample, the larger the probability that the results will be accurate. However, sample size is normally limited by practical considerations. In both I and III, data from a survey of a whole population (equipment sales in I and recorded accidents in III) and a sample were analysed. Due to the large population size in study I, the sample of private forest owners was stratified to ensure representation of all segments of interest irrespective of their relative frequency in the sample. Hence, the sample corresponded to 0.5-48.5% of the population within strata. In II, the population of households with firewood heating was considerably smaller and the sample sizes of 1,500 corresponded to 13% of the full population, which is considered more than satisfactory.

The second limitation of questionnaire surveys is that the non-respondents may differ from the responders, and thus erroneous conclusions may be drawn due to the skewed material. For practical reasons, the motives for not replying are seldom controlled. Deviations between the non-responders and responders in the sample are instead controlled using prior knowledge of the respondents (e.g. sex and holding size). In both I and III, 60% of the households that were sent questionnaires replied, which is a fairly high reply level (Trost, 2001), and analysis of prior knowledge showed no deviations between respondents and non-respondents. Since no obvious motives for not replying were identified, the fall-outs from the samples were not believed to bias the results.

Experimental studies

Since the objective in study II was to develop a suitable method for measuring tools' capacities to fell trees, it was to some extent exploratory. A number of factors important for the methodology were discovered during the study, including both the study material (the elasticity of the anchoring line) and the studied material (felling lever mechanics). Nevertheless, applicable results were obtained for validation in practical use. The results should, however, be used with caution until validated.

In IV, which examined conventional firewood-producing systems under conventional conditions, the objectives and associated considerations were very different from those of II. Based on the necessity to modify machines and operators' statements, it can be concluded that logs were longer than those normally processed. Nevertheless, the study's results are believed to have strong general applicability, at least within its range of parameters. The largest challenge in generalising the results was the influence of the operators. Possible ways to manage distortions in results arising from variations in human performance, and their limitations, are discussed below. Most of the work studied in IV was familiar and was examined by conventional techniques, but the analysis of deviations from expected work procedures was a new element. The results provided clear indications of the systems' sensitivity to both round wood features and personal skills, but were also distorted to some extent by interference from unexpected parts of the systems (the conveyors). Although examining the conveyors' influence on the work was not a defined objective of the study, it constituted an important part of the system, so the deviations they caused did not affect the study's validity.

Individual variations in efficiency have been documented in numerous studies and its related effects on generalization of results are discussed in IV. In accordance with the discussion, the study's finding of a 33% lower mean time consumption for system *proc* compared to system *cut-split* when processing wood of class 1 is probably more applicable to other operators than the absolute time difference of 29.5 min m^{-3}. However, for operators that differ greatly from the studied group in terms of demographic variables and work experience, the differences are also likely to distort relative comparisons.

Applications and suggested research

The results presented in I and III clearly suggest that self-employment in family forestry is still vibrant and is likely to continue to be so in the near future. However, the conclusions that can be drawn regarding its importance, and probable future trends, depend on whether self-employment is measured in terms of hours worked (Fig. 1), production levels or numbers of active persons.

Irrespective of the measure chosen, the number of persons self-employed in family forestry remains high. They have been proven to no longer fit the traditional stereotype of male farmers, but are nowadays a more heterogeneous group with respect to sex, ownership constellations, place of living and organizational affinities. Similar changes have been found in family forestry in general both in Sweden (Lidestav & Nordfjell, 2005) and elsewhere (Medved, 2004; Wiersum, Elands & Hoogstra, 2005). The question is whether these changes should be seen as a threat to the forest industry, which relies on timber from family forests for much of its production. In the eyes of large-scale forestry's companies, the self-employment has mainly been seen as a spare time recreational activity conducted by enthusiasts (c.f. Sennblad, 1987; Tham, 1990; Ager, 1995). Especially for logging, the activity has not been taken seriously since it has been considered irrational. Furthermore, it has not been encouraged since it obstructs the company's normal routines of using their large-scale technology and thus changes the locus of control of the logging from the buyer to the seller. In operational activities, these effects can lead to extra work for a lean, efficient organization so it is understandable that deviations from normal routines are generally avoided. However in a broader, strategic perspective, promoting self-employed family forestry might prove to be fruitful for forest industries. With an increasingly urbanised body of forest owners who are not economically dependent on their forest, the traditional arguments of increased personal income and contribution to the nation's wealth may become less important than other objectives, which do not involve logging activities. In such circumstances, if owners' engagement in forestry activities mainly involves contact with forest companies, forestry might with time become perceptually alienated and abandoned. A personal tradition of forestry work in the form of self-employment is, on the other hand, likely to yield a perception of the forest as a natural sustainable source of resources that can be both harvested and managed for multiple objectives. A parallel can be made with, for example, roads. Roads are convenient and facilitate life in many ways for the users. The roads that are used daily and lead home are much appreciated and well maintained. A road that is perceived to be of less personal use and to intrude in areas of personal interest is, on the other hand, undesired. In this sense it is natural that few persons would voluntarily allow a road expected to carry high levels of traffic to be built through their front yard, even if they appreciated its national socio-economical benefits. Analogously, a forest owner might reject the idea of logging in their mature forest, while an owner with a tradition of self-employment is more likely to see the logging as a natural step in the cyclical use of forests. A broader focus on encouraging self-employment in family forestry, irrespective of activity or extent, is thus likely to be beneficial for the future voluntary supply of raw material to the forest industry.

During the last 60 years, firewood production has seldom been included in research on forestry or forest products. In the few cases where it has been studied it has often been in the context of forest assets (Marsinko, Phillips & Cordell, 1984), energy issues (Warsco, 1994) or air pollution (Lipfert & Dungan, 1983). Its consequences for forestry and ecology have been considered less often, although there are exceptions (Driscoll, Milkovits & Freudenberger, 2000). In family forestry it has been surprisingly neglected, even though it is likely to play an important role in many ways. Its importance is indicated by the results in III, according to which 4,000 forest owning households produce firewood in a region with 6,600 family forestry holdings (with >1 ha forest) (Almqvist, 2006). Since a large proportion of family forests seem to be used to meet firewood needs, these needs are likely to influence forest management practices, in fact in many cases it is quite likely to be the main driver of forestry activities. An example is the fact that as many as 30% of the family forest owners cite firewood requirements as being an important factor in their decisions to perform pre-commercial thinning (PCT) and 69% take firewood from PCT (Fällman, 2005). It can be strongly argued that it is often the need for firewood that results in the activity rather than vice versa, since the need for heating is likely to be a much stronger incentive for the activity than good forest management and long-term economic benefits. With further incorporation of firewood production into forestry, it should thus be possible to improve family forestry's multiple uses and management of their forests. Furthermore, in a socio-economic perspective, supplies of timber and sustainable energy are not the only benefits associated with firewood production; it also has both physical and mental health benefits (Isachsen, 1984; Carlsson, 2003) and is seen as especially important since it engages many older people, as shown in III. However, there are also downsides, since as shown in III, many accidents are related to firewood processing. Ultimately, future research and governmental incentives should encourage safe firewood production according to good forest management practice, to sustain a healthy population and a valuable source of renewable energy.

Rationality in self-employed family forestry is likely to encompass more than economic factors (Ager, 1995; Törnqvist, 1995). Nevertheless, finance can be a limiting factor in investments and since standard revenue-oriented investment analyses poorly fit self-sufficiency activities, an alternative analysis was presented in IV. The analysis focuses on what is believed to be the other major limiting factor: the forest owner's time. Time and expense avoidance have previously been used in analyses of economic comparisons between self-employed work and hiring a contractor for the work (Gullberg, 1991). The analysis presented in IV builds on the same concept, but from a reversed approach. Instead of focussing on compensation per hour worked, it quantifies the hourly extra cost of saved time. The reversed approach is required for analysing the competitiveness of more efficient and more expensive equipment for a given production quantity during leisure time. The investor will then have to assess if the extra cost is acceptable, i.e. assess the value he or she places on free leisure time. The less time that is available, the higher the extra cost the investor is likely to accept. The equivalent situation in Gullberg's (1991) analysis would be if a forest owner for whom it would be economically advantageous to do work him/herself, would nevertheless decide to hire a contractor in order to gain free leisure time.

Sales of equipment suitable for self-employed forestry were surveyed in I, and the results showed that there were large variations in both price and efficiency levels. The economic aspects of efficiency and required work time have already been discussed, but there is also a safety-oriented aspect as touched upon in III. Use of more efficient equipment for a given production volume would decrease the already low amounts of work time spent per active forest owner, but its effects in terms of accident risks are debatable. Low exposure time for the risks might statistically imply low probability of an accident, but has also been argued to increase accident rates due to the lack of practice in handling the seldom encountered risks (Weegels & Kanis, 2000; Fischer *et al.*, 2005; Elvik, 2006).

The method developed in II proved to be suitable for assessing the performance of tree-felling tools and for developing efficiency models for manual tree felling. With increased knowledge of critical limits in the felling of difficult trees and the use of available felling tools, the work could be made less strenuous and decrease both human injuries and damage to property. On the other hand, this could also increase risks to some extent, since it has been argued that people tend to increase the riskiness of their work behaviour when provided with personal protection gear and safer equipment, (Klen & Väyrynen, 1984) if they see efficiency benefits from maintaining risk levels they have previously accepted (Hale & Glendon, 1987). Analogously with the constant risk level, a desire to retain familiar efficiency levels could be involved in the violations of safety standards found in III. For instance, the introduction of the two-hand controls on wedge splitters may hypothetically have contributed to the high level of people working together rather than alone found in III. An additional worker could be the consequence of a desire to compensate for the lost helping hand and the resulting decreased efficiency in chunk loading. Preventative measures certainly also improve safety (Hale & Glendon, 1987) despite the possible backfires mentioned above, but it can be concluded that the effect of un-evaluated measures, although intuitively sound, is not always obvious.

Besides the discussion above, this thesis has not touched upon or evaluated suitable accident preventive methods. However, previous research on the subject has found structural changes (e.g. product modifications) as well as tailor made two-way communication programmes carried out in small groups to have long term effect (Lund & Aarø, 2004). One-way information (e.g. mass media campaigns, posters, leaflets and films) produce very little effect, except when the target group is highly motivated, while the interaction of different measures and long-lasting efforts seem to yield long term effects (Lund & Aarø, 2004). However, the effects of structural changes are not always obvious as discussed above, and other efficient methods are not easily applied on self-employed family forestry. Both I and III pointed out the heterogeneity and the dispersal of self-employed family forest owners, which imply difficulties in effective extension services for both accident prevention and forest management. To find effective measures to generate both safe and efficient work behaviour is thus an important challenge for future research.

Conclusions

The overall objective of examining key issues concerning efficiency and safety was put into context in Figs. 3 and 4 in terms of activities and factors influencing self-employed family forestry. The studies underlying this thesis have shown that large numbers of people are engaged in this activity, and that within the studied areas there are good conditions for conducting safe and efficient self-employed work. Despite the scope for working safely, the studies show that accidents are common. These to some extent conflicting findings may originate in the rich diversity found in self-employed family forestry, both between workers and within a given worker's activities. The possibility to adapt and use the most suitable technique and to update knowledge are limited if the activities are diverse and far apart in time. Attempts to minimize costs also imply a restricted investment policy, which might result in use of less efficient or even inappropriate equipment compared to that available on the market. In other words, knowledge of the working situations in self-employed family forestry is essential for understanding the underlying causes of accidents (cf. Fig. 4). With further information on motives for the work, behaviour during the work, investments and risk management it should be possible to develop more efficient methods to facilitate this heterogeneous group's work and to prevent accidents.

Finally, it is worth noting that there are a number of good reasons to encourage self-employment in family forestry for both the forest industry and the government. This will, however, require further promotion of the activity and awareness of the conditions affecting it, especially in terms of its irregular work patterns for self-sufficiency and recreational purposes.

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Svensk sammanfattning (Swedish summary)

Effektivitet och säkerhet inom självverksamt familjeskogsbruk

Med självverksamt skogsbruk menas det arbete som skogsägaren eller dess medhjälpare (tex familjemedlemmar) utför på den egna skogsfastigheten. För avverkningsarbetet används olika metoder inom det självverksamma skogsbruket och det storskaliga, industriellt inriktade skogsbruket. Det storskaliga skogsbruket är helmekaniserat med skördare och skotare, medan det i självverksamt skogsbruk används en kombination av motormanuellt (motorsåg) och mekaniskt (utkörnings med tex traktor och griplastarvagn) arbete. Röjning och plantering utförs dock med samma metoder inom både storskaligt och självverksamt skogsbruk. Minskade mängder levererat virke från självverksamt skogsbruk och storskogsbrukets överlägsna effektivitet har av många tagits som signaler på att självverksamheten inom skogsbruket var på väg att dö ut. Trots signalerna så utgör självverksamt skogsarbete fortfarande hälften av den årliga arbetstiden som läggs ned på praktiskt skogsarbete och står tyvärr också för större delen av olyckorna. Trots omfattningen av både arbetsinsatsen och olyckorna finns det dock lite kunskap om självverksamheten. Den här avhandlingen har därför haft som syfte att analysera effektivitet och säkerhet inom det självverksamma skogsbruket, inklusive vedarbete. De fyra studierna som genomfördes återfinns i appendix I-IV.

Enkätudersökningar utförda i I och III visade att självverksamt skogsarbete och även vedupparbetning (kapning, klyvning etc.) är vanligt förekommande och det fanns inga signaler på minskning inom den närmsta tiden. Två tredjedelar av skogsägarna utförde självverksamt skogsarbete i form av avverkning, utkörning, plantering eller röjning (I). De som var självverksamma skilde sig åt från dem som inte var det, bla genom lägre ålder och större andel män. För vedarbetet så var antalet olyckor högt i förhållande till nedlagd arbetstid (51 olyckor per miljon timmar) och just arbetstiden förklarade mer av olycksförekomsten än antal aktiva personer, kön och ålder (III). Arbete med kilklyv (tex hydraulklyv) var överrepresenterat i olycksstatistiken.

Eftersom det fallande trädet står för merparten av dödsfallen inom skogsbruket utvecklades en metod för att utvärdera kapaciteten hos redskap för riktad trädfällning (II). Metoden möjliggjorde mätning av redskapens förmåga att tvinga stammen i önskad riktning efter att rikt- och fällskär hade sågats ut. Nyttan av sådana mätningar demonstrerades teoretiskt i form av redskapets förmåga att klara av lutande träd. Effekten av ökad mekanisering av småskalig vedupparbetning studerades i en experimentell studie (IV). Maskinkombinationen klingkap-hydraulklyv jämfördes med en kombimaskin, där effektiviteten var 25-33% högre för kombimaskinen (dvs systemet med högre mekaniseringsgrad).

Baserat på resultaten diskuteras självverksamhetens inverkan på det svenska skogsbruket. Engagemanget i praktiskt skogsbruk anses som en viktig del i en fortsatt frivillig försörjning av skogsråvara till skogsindustrierna från privatägd skogsmark. Självverksamheten borde därför uppmuntras och ytterligare uppmärksamhet borde ägnas åt verksamheten och dess speciella förhållanden för att kunna förbättra effektiviteten och säkerheten.