**Dissertationes Forestales 287**

# Inter-disciplinary analysis for synthesising weevil damage and stakeholder perception related to stump harvesting

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Academic dissertation

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## ABSTRACT

Stump harvesting for bioenergy production is an option for by which the forestry sector in Finland can accelerate the development of a green economy, which is also known as a bioeconomy. Furthermore, it contributes to the discussion on how stump harvesting affects pest management. This dissertation analysed and synthesised stump harvesting for bioenergy production in terms of sustainability, especially in terms of forest health and societal acceptance. This research consequently used an interdisciplinary approach. The effects of human intervention by stump harvesting on pine weevil (*Hylobius abietis*) breeding, feeding, and seedling damage was studied via field experiments. Stakeholder perception and acceptance of stump harvesting were studied via questionnaires and a literature review. Field experiments showed that stump harvesting is a secondary tool in the regulation of pine weevil breeding and feeding. The questionnaires indicated that respondents were divided on the topic of to stump harvesting for pine weevil reduction, site preparation, and bioenergy production. Furthermore, the social acceptance study found that there have been contradictory research findings in this regard over the past decades. Consequently, society remains confused about stump harvesting for bioenergy production. According to the questionnaires, high level administrators were especially critical of stump harvesting whereas farmers and foresters were in favour of this practice. As Finland aims to be a bioeconomy pioneer, it needs to consider updated knowledge on and social acceptance of stump harvesting for bioenergy production. In addition, technological investment and market acceptance of stump harvesting contribute to the bioeconomy. Future research therefore needs to focus on the policy implications of stump harvesting with updated technological guidelines that consider stakeholder perceptions.

**Keywords:** bioeconomy, bioenergy production, pine weevil, social acceptance, human intervention

## ACKNOWLEDGEMENTS

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Abul Rahman
Joensuu, 2020

## LIST OF ORIGINAL ARTICLES

This dissertation is based on the following four articles, which will be referred to as Articles I–IV in the text. They are reprinted with the permission of the publishers.

I Rahman A., Viiri H., Pelkonen P., Khanam T. (2015). Have stump piles any effect on the pine weevil (*Hylobius abietis* L) incidence and seedling damage? Global Ecology and Conservation 3: 424-432. https://doi.org/10.1016/j.gecco.2015.01.012

II Rahman A., Viiri H., Tikkanen O-P. (2018). Is stump removal for bioenergy production effective in reducing pine weevil (*Hylobius abietis*) and *Hylastes* spp. breeding and feeding activities at regeneration sites? Forest Ecology and Management 424: 184-190. https://doi.org/10.1016/j.foreco.2018.05.003

III Rahman A., Khanam T., Pelkonen P. (2017). People’s knowledge, perceptions, and attitude towards stump harvesting for bioenergy production in Finland. Renewable and Sustainable Energy Reviews 70: 107-116. https://doi.org/10.1016/j.rser.2016.11.228

IV Rahman A., Khanam T., Pelkonen P. (2019). Is stump harvesting for bioenergy production socially acceptable in Finland? Journal of Cleaner Production 229: 1233-1242. https://doi.org/10.1016/j.jclepro.2019.05.045

Author’s contribution: Abul Rahman was mainly responsible for analysing the data and writing all of the above-mentioned articles. The co-authors and supervisors participated in formulating the research tasks and commented on the manuscripts. Data and certain methods for Article II were respectively collected and formulated by co-author Heli Viiri.

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## SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| CA | Community acceptance |
| CHP | Combined heat and power plant |
| FSC | Forest Stewardship Council |
| MA | Market acceptance |
| SPA | Socio-political acceptance |
| SWOT | Strengths, weaknesses, opportunities, and threats |

# 1. INTRODUCTION

## 1.1. Role of stumps in bioenergy production

Fossil fuels are a major source of $CO_2$ emissions and, consequently, global warming. In the Paris agreement, most countries pledged to arrest the rise in global temperature to below 2 °C (UNFCC 2016). The use of renewable energy can contribute to the fulfilment of this pledge. Renewable energy is of interest not only to policy makers, professional stakeholders, and scientists in the energy sector, but also to scientists in many other sectors and even consumers. Woody biomass, in particular, has received considerable policy attention (International Energy Agency 2011). In 2017, Finland met 36% of its total energy demand by using renewable energy sources (Statistics Finland 2018), and the European Union (EU) aims to reduce European continental greenhouse gas emissions by 80–95% by 2050 (COM 2011). Bioenergy is a form of renewable energy that can significantly contribute to the mitigation of climate change. In addition to the climatic benefits, the bioenergy sector provides social benefits, especially with respect to employment and rural development. Bioenergy comprised 27% of the total Finnish energy sector in 2017 (Statistics Finland 2018) and is the major type of energy used in heating in Finland. The utilisation of forest-based biomass ensures high efficiency in combined heat and power production (CHP) plants.

The primary forest bioenergy resources are thinning from forests, logging residues from final felling and stumps with thick roots. Secondary bioenergy resources include black liquor from pulp industries, sawdust, and waste wood. Stump wood has a high calorific value (Eriksson and Gustavsson 2008) and is therefore an especially attractive bioenergy source in Finland. Stump wood utilization for bioenergy production can be one competitive alternative not to increases annual felling and secure timber supply and pulpwood industries. There is a long history of stump harvesting for tar production in Sweden and Finland (Anerud 2012). In 2001, the Finnish company UPM Kymmene started commercial stump extraction and has burned stump wood in CHP plants to produce heat and electricity (Paananen and Kalliola 2003). Stump harvesting reduces the prevalence of root rot (*Heterobasidion annosum*) and has been adopted in the UK, Italy, British Columbia (Canada), and the north-western USA (Cleary et al. 2013). In addition to root rot control, stump harvesting is also relevant to bioenergy production in British Columbia (Berch *et al.* 2012) and the UK (Price 2011). Unlike that of Sweden, Finland's Forest Stewardship Council (FSC) certification only restricts the site types and number of harvested stumps per site, but it does not limit the area of stump harvesting (FSC 2012). The possibilities for maximum sustainable stump harvesting was estimated at 7.94 million $m^3$/y in 2015–2024 in Finland (Statistics Database 2019).

Traditionally, stump harvesting has not been profitable. However, after the development of stump harvesters, the use of stumps in CHP plants has become more popular. Stump wood chip consumption in Finland has gradually increased to 1.1 million $m^3$ in 2013 but has decreased since 2014. In 2017, Finnish heat and power plants consumed around 7 million $m^3$ in forest chips, including 0.5 million $m^3$ in stump wood chips (Luke Statistics 2019). During the last decade, there has been much discussion and research on stump harvesting. Stakeholders are concerned about its economic viability, environmental consequences, and technological requirements as well as attitudinal barriers and knowledge restrictions (Persson et al. 2017).

### 1.2. Sustainability of stump extraction

Sustainable forest management involves human intervention in forest ecological processes and structures, such as biodiversity (EC 2018). In Finland, this is done by industrial timber and bioenergy production from woody biomass resources as well as by tourism, biodiversity management, and carbon sequestration. Timber harvesting has economic, ecological, and societal consequences. For example, it increases pine weevil (*Hylobius abietis*) feeding damage, because fresh clear-cut stumps are the preferable breeding and feeding resource of this pest. Furthermore, bioenergy production from forest resources face environmental, socio-cultural, and economic criticism (Upham 2011). Public opinion and acceptance are vital social factors in implementing new energy concepts and an important part of sustainable development (Assefa and Frostell 2007). With regards to bioenergy resources replacing the use of fossil fuels, people's decisions can be affected by the poor availability of up-to-date scientific information (Robbins 2011).

In terms of sustainability, stump harvesting needs to be environmentally appropriate, socially beneficial, and economically viable. After conducting several projects to determine the impacts of stump harvesting on the climate and environment of Sweden, the Persson et al (2017) declared that stump harvesting has positive effects on the climate, reduces root rot, and is neutral to the discharge of methyl mercury. Economically, stump harvesting can improve site preparation (Saarinen 2006) and reduce the cost of seedling regeneration. It further generates new raw materials for bioenergy production, thus contributing to the bioeconomy.

Increased stump harvesting nonetheless has adverse environmental effects, including decreased future site productivity, degradation of soil physical structure, and immediate $CO_2$ release (Walmsley and Godbold 2009; Moffat et al. 2011). In addition, in terms of aesthetic considerations, the public have shown negative reactions towards stump removal (Gundersen 2016). There are ongoing discussions and research concerning the positive and negative impacts of stump harvesting. Such discussions have become heated in Finland through public media. For example, Kivipelto (2011) argued that stump harvesting has continued despite poor knowledge of its environmental effects.

Scientific studies on the growing concern about the environmental and biodiversity effects of stump harvesting are ongoing. Evidently, there are gaps in the publicly available information regarding stump harvesting, which has created uncertainty about its implications, possible benefits, and overall impacts among stakeholders. In terms of decision-making, it is necessary to sway stakeholder attitudes and opinions regarding stump harvesting for bioenergy production. With increasing information in this area, forest owners may be encouraged to advance stump harvesting for bioenergy production, which can influence the social acceptability of this practice.

### 1.3. Forest health and stump extraction: the pine weevil problem

In the northern Europe, the UK, and parts of central Europe, logging primarily follows the clear-cutting method, which may be the primary cause of pine weevil damage (Långström & Day 2004). In the UK, the government attempted to find innovative methods against pine weevil damage, which results in huge economic losses of GBP 40 million annually (Government of the United Kingdom 2018). Pine weevil can damage up to 60–80% of planted seedlings if proper protection measures are not taken (Örlander and Nilsson 1999). Innovative and efficient solutions for protecting seedlings from pine weevil damage need to be studied relative to the timing of pine weevil migration and their life cycles. For instance, adult pine weevils prefer to migrate at 18 °C (Solbreck and Gyldberg 1979) and have the ability to travel for 10 km or more (Solbreck 1980). It has been estimated that almost 14,000 adult weevils per hectare could be present in clear-cut areas (Nordlander et al. 2003), which are especially suitable for pine weevil breeding and feeding. Tree stumps in clear-cut areas are a key element in the pine weevil life cycle. In early summer, the odour of fresh clear-cut stumps lures pine weevils to new clear-cut areas (Nordenhem and Eidmann 1991). Female pine weevils start laying eggs in the stumps, their roots, or the soil near the roots (Nordlander et al. 1997); those from the *Hylastes* spp. can also lay eggs in fresh clear-cut stumps (Lindelöw et al. 1993). Weevils mature after 14 months to 4 years depending on the environment (Beijer-Petersen et al. 1962; Långström 1982). Mature weevils emerge from stumps and roots and start to feed on the bark and phloem of coniferous trees. Pine weevil feeding results in the girdling of seedlings, if they are planted without proper protection, which ultimately causes seedling mortality. Severe pine weevil damage continues up to three years after an area has been clear-cut (Långström 1982; Nordenhem 1989; von Sydow 1997; Moore et al. 2004).

In Finland, 120,500 ha of forest was harvested by clear-cutting, on average, from 2007−2013 (FFA 2014); 141,000 ha of forest was harvested by clear-cutting in 2016 (Luke E-year book 2017). Almost 400–600 stumps per ha are typically harvested from a suitable site in Finland (Äijälä et al. 2010). Theoretically, removing fresh stumps from the clear-cut areas, would reduce pine weevil breeding and feeding resources. This could be considered a silvicultural method in integrated forest pest management to manage pine weevils and as an alternative to chemical methods of protecting seedlings against pine weevil damage. Practically, however, it is not possible to remove all stumps from clear-cut areas. Stump-harvesting guidelines recommend that at least 25 stumps (more than 15 cm in diameter) per ha should remain in clear-cut areas for ecological purposes (Koistinen et al. 2016). In addition, due to the high cost of excavations, stumps with diameters less than 20 cm are often left in place (Kärhä 2012). After harvesting, stumps are piled along the roadside near the clear-cut area and may still attract pine weevils. According to Skłodowski (2017), piles of branches can support Coleoptera beetles. Removing the stumps from the clear-cut area to reduce pine weevil infestation is still not scientifically proved to prevent it altogether. This apparent insufficiency is one reason to investigate the additional benefits of stump harvesting, including additional income, site preparation, bioenergy production, and improvements in the social perception of the acceptability of stump harvesting.

In this context, stakeholders of stump harvesting practices (forest owners, managers, companies, and forestry professionals) need proper knowledge of the relationship between pine weevil infestation and stump harvesting. Similarly, to obtain a holistic understanding of stump harvesting, ecologists need to cooperate with sociologists, politicians, economists, and society at large.

### 1.4. Social acceptance of stump extraction: insufficient knowledge of stakeholder opinion

The forestry sector continuously demands new evidence and updated knowledge on the positive and negative environmental impacts of stump harvesting. Moreover, updated knowledge is required by the public, media and environmental non-governmental organisations, amongst others. If Finland wants to move towards a bioeconomy, knowledge of stakeholders' perceptions and attitudes towards biological resources is vital. Moreover, if research can show that stump removal reduces pine weevil damage, it would be a reason for providing additional support to stump-based bioenergy production and commercial stump harvesting, both of which are vital to establishing commercial stump harvesting in Finland.
Generally, stakeholders mean individuals or groups who may affect or may be affected, with the objectives of an organization (Freeman and Reed 1983). In the field of bioenergy, stakeholders are mainly categorized into internal and external stakeholders. Internal stakeholders  are directly involved in the bioenergy supply chain . Citizen, resident, NGO and governmental organizations are external stakeholders.

Energy sector in general is one of the critical and vulnerable societal areas. In Finland, especially in rural regions the consumers realize the value of energy safety during destructive winter storms. For instance, according to coast-disasters related hazard and risk analysis the two main dimensions of stakeholders are power and interest. The profile of the stakeholders can be categorised in four groups (latents, promoters, apathetics, defenders) according to the changing two dimensions. Stakeholders who have high power and high interest in a project are the most influential with respect to the development of a field. (Stakeholders dimensions 2019). Another aspect related to social psychological bases for stakeholders is their capacity of acceptance. The capacity of acceptance is greatly related to knowledge and understanding, as well as to values and beliefs (Zinn et. al 2008).

For an applied research task public knowledge, opinion, and attitude significantly impact the development of new environmental ideas, sources, and issues that are much discussed in broader society (Milfont et al. 2010). Knowledge means knowing something either officially or casually (Lambrinou et al. 2009), and attitudes refer to people's moods and understanding and acceptance of an idea (Bagozzi and Burnkrant 1979).

Social acceptance shows the extent to which a new idea is accepted or tolerated by the public. Typically, socio-political acceptance (SPA), community acceptance (CA) and market acceptance (MA) are the dimensions of social acceptances. Generally, SPA means a new idea that is accepted by the public, stakeholders and policymakers, where CA mainly deal with trust and market acceptance deal with facts that are accepted by stakeholders. In the renewable energy sector, social acceptance is a significant issue, and Devine-Wright (2007) indicated that public support is an important tool for applying renewable energy technologies. For example, public acceptance of bioenergy can accelerate the growth of the bioenergy market (Magar et al. 2011). Similarly, public acceptance of stump harvesting can contribute to knowledgeable scientific and policy discussions on stump wood for bioenergy production. Researchers therefore need to recognise the public reaction to stump harvesting, and policy makers should consider the public's view. For the development of stump harvesting, public acceptance of this practice for bioenergy production should be studied, and it should include scientific research and stakeholders' views.

Knowledge of the public's acceptance of stump harvesting will contribute to the development of the stump wood industry for the bioenergy market. However, little research has been done on the impact of stump harvesting on pine weevil damage and public acceptance of and views on this issue.

One approach to analyse, understand, and synthesise this complex issue is to conduct interdisciplinary research (Figure 1). Interdisciplinary refers to a synthesis of various disciplinary viewpoint to study a theme or new idea (Choi and Pak 2006). Multidisciplinary refers that different discipline will provide knowledge within each disciplinary boundaries (Choi and Pak 2006). In terms of decision making, relevant scientific research on stump harvesting is usually time-consuming and varies among disciplines, e.g. ecology, sociology, and economics. However, an interdisciplinary study that aims integrating understanding and methods from different disciplines, can combine social acceptance and knowledge of stump harvesting with ecological consequences for a practical synthesis in a wider context. The SWOT analysis was carried out to address the strengths, weaknesses, opportunities, and threats about stump harvesting within the boundary of this thesis results. By enhancing readability of the main results, SWOT helps to understand the stump harvesting risks and opportunities of success.

### 1.5. Objectives

The overall aim of this dissertation was to answer the following question: 'Does stump harvesting practice meet sustainability criteria and is it effective for bioenergy production in the context of Finnish forest health and society?'

Subsequently, the inter-disciplinary objectives of this dissertation were as follows:

1. To investigate how stump harvesting affects pine weevil breeding and feeding activity in clear-cut areas (Articles I and II).
2. To study the knowledge, perceptions, and acceptance of stump harvesting in Finnish society (Articles III and IV).

## 2. MATERIALS AND METHODS

### 2.1 General framework

Figure 2 depicts the overall framework of the dissertation. Stump harvesting was studied using field experiments, questionnaires, and a literature review. Findings from the field experiments (Articles I and II) and questionnaire (Article III) were used to study issues regarding commercial stump harvesting. Findings from the previous two decades of stump harvesting research (Article IV) were reviewed, where social acceptance dimensions were used to justify the development of the stump harvesting process. Positive and negative findings regarding stump harvesting were also considered.

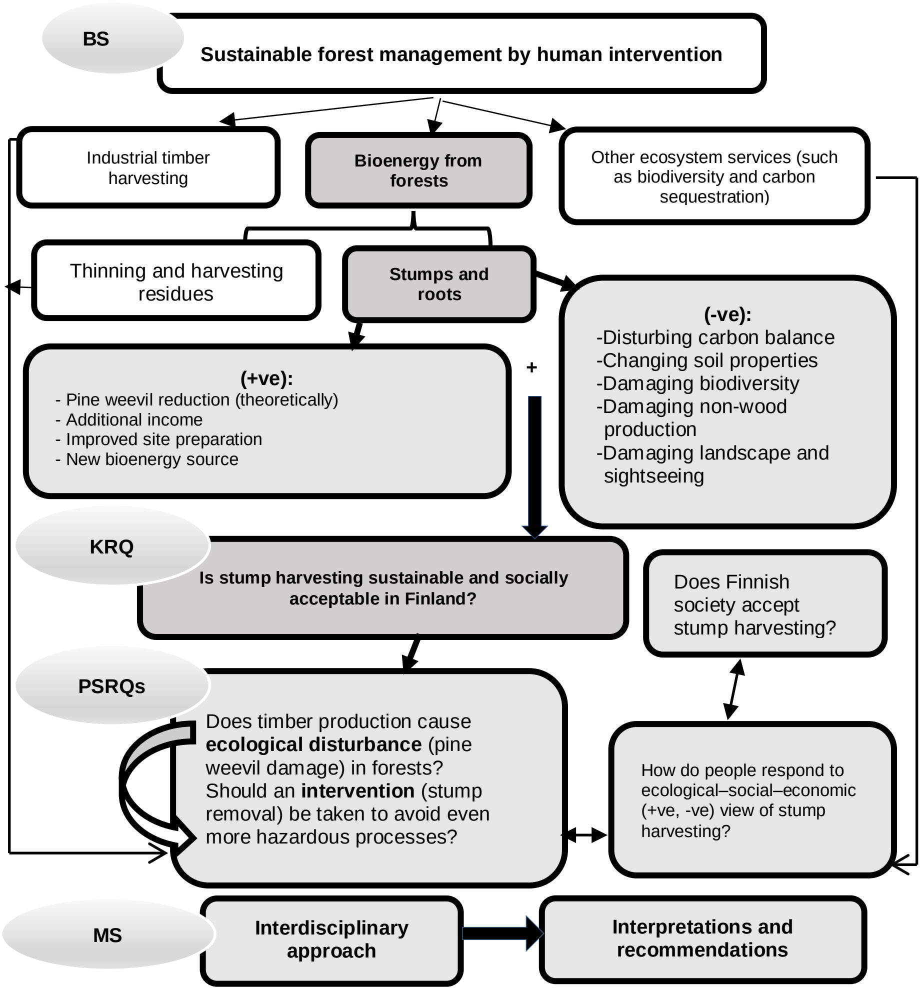


**Figure 1.** Culminated coordination boundaries of this study (BS: background of the study; KRQ: key research question; PSRQs: paper-specific research questions; MS: methods of the study; +ve: positive; -ve: negative).

## 2.2 Stakeholder intervention (Articles I and II)

### *2.2.1. Stump pile and seedling damage (Article I)*

Article I inspected the occurrence of and damage caused by pine weevils (*H. abietis*) in a single stump plot (SSP; forest logging and regeneration sites at which stumps are stored in a large single pile), a multiple-stump plot (MSP; the stumps were stored in multiple small piles spread throughout the regeneration area), and a no-stump extraction plot. Pitfall traps (Figure 3a) were installed at eight sites in North Karelia, Finland (Table 1), five of which were stump-extracted sites; three were SSPs, two were MSPs (Figure 3b). Three other sites, the no-stump extraction plots, were control sites. A total of 320 traps (40 at each site) were installed in May 2010 and May 2011. Traps in the MSP sites were installed in four rows between the stump piles, and while those in SSPs were installed in four rows close to the stump pile (Figure 3b). The trapped adult weevils were collected twice a month at two-week intervals and brought to the laboratory for identification.

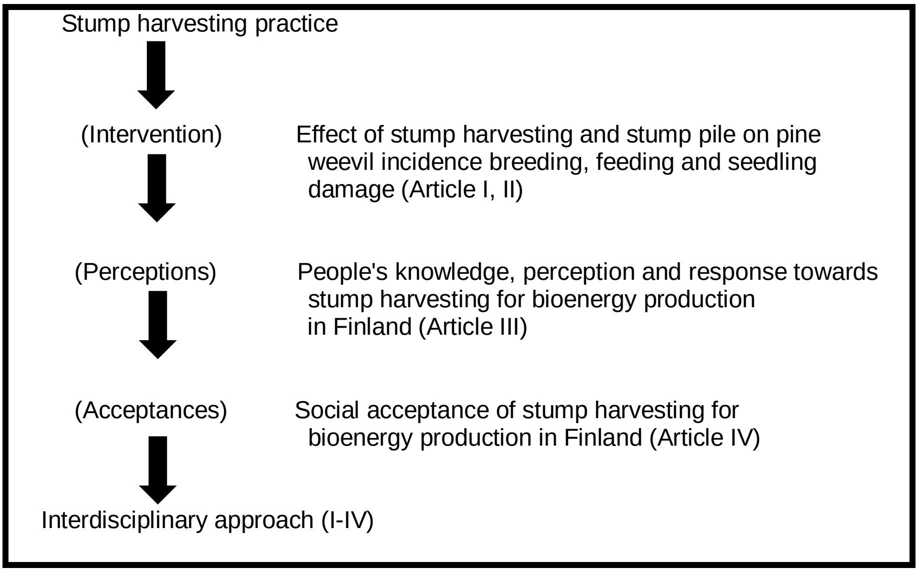


**Figure 2**. General framework of the dissertation.

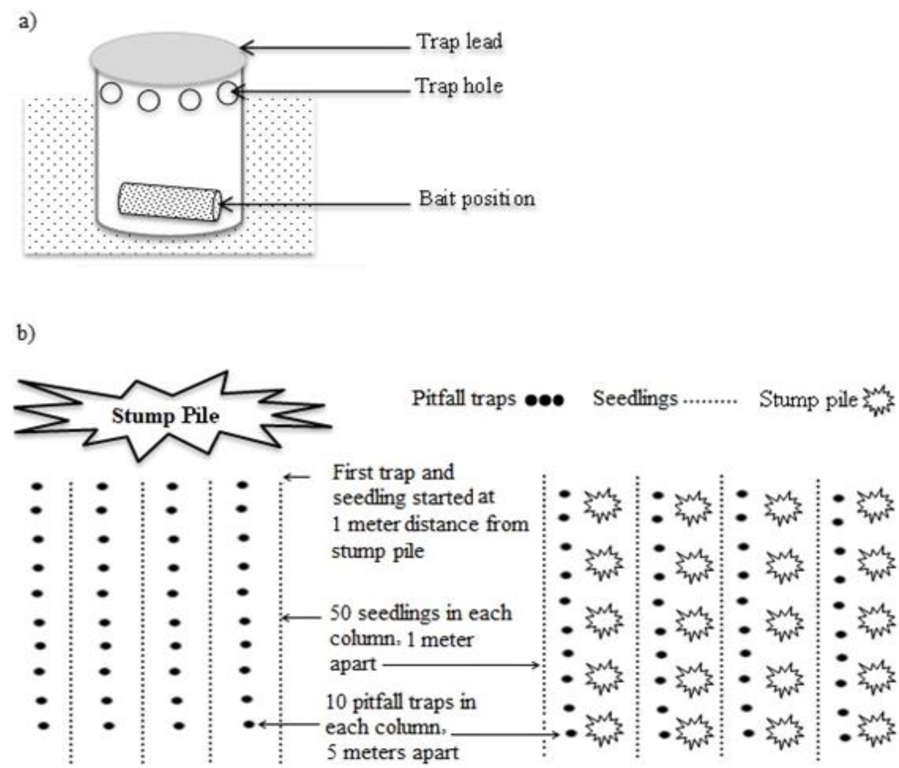


**Figure 3.** a) Pitfall traps, b) arrangement of seedlings and traps in the single-stump plots and control plots (on the left) and multiple-stump plots (on the right).

**Table 1.** Description of field experimental sites of the study reported in Article I

| Site name | Area, ha | Amount of wood, $m^3$ | Logging time month/year | Stump removal time (month/year) |
|---|---|---|---|---|
| Nuottilampi | 5.3 | 2048 | Part 08/2008 Rest11/2009 | 11/2009 |
| Rypymäki | 5.7 | 1834 | 10/2009 | 05/2010 |
| Jokikumpu | 8.2 | 2584 | 12/2009 | 05/2010 |
| Särkipuro | 11.4 | 3218 | 10/2009 | No stump removal |
| Seponvaara | 3 | 833 | 12/2009 | 9/2010 |
| Uskali | 9.4 | 3437 | 9/2009 | 8/2010 |
| Värtsilä 1 | 3.3 | 1090 | 4/2010 | No stump removal |
| Värtsilä 2 | 3.3 | 1090 | 4/2010 | No stump removal |

In the control sites, traps were installed along the roadside. In each site, 200 seedlings were planted in a row and alternated with traps. Damage from pine weevil feedings was subsequently classified according to Heiskanen and Viiri (2005), as no damage, less than 25% of the stem circumference of seedling gnawed, 25–50% of the seedling circumference gnawed, more than 50% of the seedling circumference gnawed, or an almost entirely gnawed circumference, and dying or dead seedling. Data from the soil in which the each seedlings were planted were collected from all sites.

*2.2.2. Remaining roots and larval density (Article II)*

Article (II) investigated how timing of stump removal interrupts the pine weevils and *Hylastes* species breeding and abundance. In this study, 320 experimental plots (1 $m^2$) were established in 16 clear-cut sites. The experiments were conducted in paired control and stump-removal sites based on approximately equal standing stock volume of the previous coniferous forest (Table 2). Based on time lag differences between logging and stump extraction, sites were divided into short-delay (logging year 2010 to stump extraction year 2010) and long-delay (logging year 2009 to stump extraction year 2010) groups. Only coniferous root samples were collected for laboratory examination in 2012 and 2013 in order to study the effect of treatment on availability of breeding material presence of *H. abietis*. The diameter and length of 8 896 root samples were measured to calculate the root surface area. The percentage of each root gnawed by *Hylobius* was determined, and gnawed root surface area was calculated as follows:

$$\text{Surface area of each root} \times 100/\text{gnawed percentage for each root} \quad (1)$$

It was assumed that one gnawed root sample represented one pine weevil larva. The following mixed linear model was developed:

$$\text{Log } Y_{ij} = \log \beta_1 + \log \beta_2 \, T_{ij} + \log \beta_3 \, \delta_{ij} + \log \beta_4 \, \theta_{ij} + \varepsilon_{ij} \quad (2)$$

In this model, $T_{ij}$ is treatment T ∈ {Control (i.e. no stump removal), $\delta_{ij}$ is treatment × time (short, long), SR (stump removal)}, *i* is the site, *j* is the paired sites (control, stump removal), $\theta_{ij}$ is the stand volume, $\varepsilon_{ij}$ is the error term, $\beta_1$ is a constant, and $\beta_2$, $\beta_3$, and $\beta_4$ are coefficients of the corresponding variables in the model.

Data analysis was carried out via the SPSS Statistics software package (SPSS for Windows, version 19.0, SPSS, Chicago, IL).

**Table 2**. Field experimental sites for the study reported in Article II

| Site name | Pair code | Logging volume ($m^3$/ha) | Area, ha | Logged | Stump extraction |
|---|---|---|---|---|---|
| Uimaharju | P1 | 223 | 0.73 | 2009 | No |
| Katajavaara | P1 | 237 | 0.89 | 2009 | 2010 |
| Korpivaara | P2 | 260 | 0.91 | 2009 | No |
| Havukkavaara 1 | P2 | 287 | 2.95 | 2009 | 2010 |
| Kokonsalmi | P3 | 234 | 0.70 | 2009 | No |
| Havukkavaara 2 | P3 | 244 | 3.42 | 2009 | 2010 |
| Rempsu | P4 | 256 | 1.97 | 2009 | No |
| Juurikka | P4 | 260 | 1,12 | 2009 | 2010 |
| Petrumansalo | P5 | 294 | 2.93 | 2009 | No |
| Juurikkajärvi | P5 | 298 | 2.07 | 2009 | 2010 |
| Polvijärvenniemi | P6 | 304 | 0.92 | 2010 | 2010 |
| Jalaslampi | P6 | 301 | 1.19 | 2010 | No |
| Polvijärvensalmi | P7 | 262 | 2.23 | 2010 | 2010 |
| Kermansalo | P7 | 258 | 0.95 | 2010 | No |
| Valkeinen | P8 | 267 | 0.43 | 2010 | No |
| Arhinmäki | P8 | 265 | 3.43 | 2010 | 2010 |

## 2.3. Stakeholder perceptions and acceptance (Articles III and IV)

### *2.3.1. Questionnaires (Article III)*

The questionnaire was prepared for the Silva Fair in 2013 in Joensuu, Finland, where people from around the country gathered to learn about the latest developments in the forestry sector. A total of 12 questions were asked in four sections: basic information and respondents' knowledge of, opinion about, and attitude towards stump harvesting. Nominal and five-point Likert scales (strongly agree = 1, agree = 2, no opinion = 3, disagree = 4, and strongly disagree = 5) were used. A knowledge index for respondents was formulated based on the knowledge questions. According to the World Bank Institute (2009), '[t]he knowledge Index is the rankings average of the presentation of a territory in three areas of the so-called Knowledge economy, namely, education, invention and information and communications skill'. In the questionnaire, respondents' knowledge answers were categorised as correct (2), slightly correct (1), and wrong (0). Because of the scientific terms used in the questionnaire and the translation from English to Finnish, we included slightly correct answers to obtain in-depth knowledge on stump harvesting. Based on the respondents' answers, we distinguished four levels of the knowledge index (< 0.5 = very poor, 0.5–1 = poor, 1.01–1.5 = good, and > 1.5 = very good). Both positively and negatively worded questions were posed in the opinion section, and the attitude section posed mainly positively worded questions. In total, 166 out of 175 answered questionnaires were valid for analysis (Table 3).

**Table 3.** Percentages of respondents' characteristics related to gender, forest ownership and forestry background (N=166)

| Male (%) | Female (%) | Forest owner (%) | Non-forest owner (%) | Forestry background (%) | No forestry background (%) |
|---|---|---|---|---|---|
| 53 | 47 | 68 | 32 | 62 | 38 |
| 100 | | 100 | | 100 | |

*2.3.2. Stakeholder acceptance (Article IV)*

The questionnaire from Article III) was explored further to understand stakeholder acceptance of stump harvesting. The article combined a literature review of stump harvesting and questionnaire results linked to three main dimensions of public acceptance (socio-political acceptance, SPA; community acceptance, CA; and market acceptance, MA) introduced by Wüstenhagen et al. (2007). In the literature review, relevant research studies from the previous two decades were divided into findings that supported stump harvesting and those that did not. These were also linked to the different dimensions of public acceptance. Our questionnaire focused on positive perceptions of stump harvesting because public acceptance of a specific issue depends on positive outcomes (Figure 4). According to Näyhä (1977), respondents were categorised into six groups: higher level administrators, lower level administrators, skilled workers, farm and forestry workers, students and pupils, and others. The eight questions asked were categorised as SPA, CA and MA (Figure 4).

# 3. RESULTS AND DISCUSSION

Articles I and II provided new explanations for the effect of stump harvesting on pine weevil activity. Opinions regarding the benefits of stump harvesting in terms of additional income, site improvement, and new bioenergy resources are justified in Article III, and overall acceptance of stump harvesting is validated in Article IV. The major findings are provided below; more detailed expositions of the results are presented in the respective original articles.

CA= Community acceptance; SPA= Socio-political acceptance; MA= Market acceptance

I would like to-
1. Use fuels from stumps
2. Promote stump harvesting to friends and family members or in a public hearing (like seminar)
3. Push politician to promote stump harvesting

I think-
4. It increase production of wood fuel
5. Forest owners earn revenue from stump energy
6. Stump harvesting improve site preparation
7. Stump removal reduce pine weevil insect damage to seedlings
8. Stump removal reduce root rot diseases

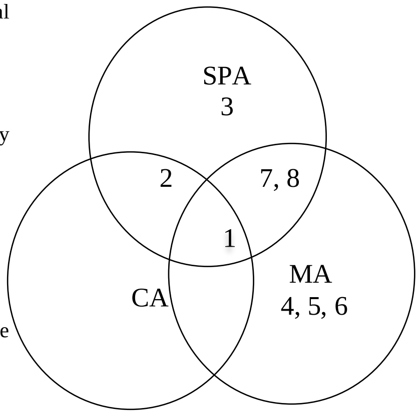


**Figure 4**. Link between survey questions and public acceptance dimensions.

## 3.1. Stakeholder intervention

### *3.1.1 Effect of stump piles on incidence of and seedling damage by pine weevil*

Article I reported that weevil incidence was reduced in single stump pile sites compared to that in areas with multiple stump piles (Figure 5). Pine weevil incidence depended on the number and spatial placement of stump piles in a clear-cut area. Possible reasons for weevils being attracted to stump piles include the emission of volatile compounds, such as monoterpene and ethanol (Brattli et al. 1998). Stump piles on multiple stump sites were kept within the clear-cut area, and adult weevils consequently found suitable breeding places and resided longer compared to those in single stump piles. Pine weevils arrive and start breeding in clear-cut areas in early summer (Solbreck and Gyldberg 1979). Pine weevil occurrence varies depending on the previous forest stand, logging, stump harvesting method, and total regeneration process of the area (Viiri 2008). According to the results in Article I, stump harvesting may reduce the weevil population, but if stumps are stored in piles in logging site it can attract more pine weevils in the area.

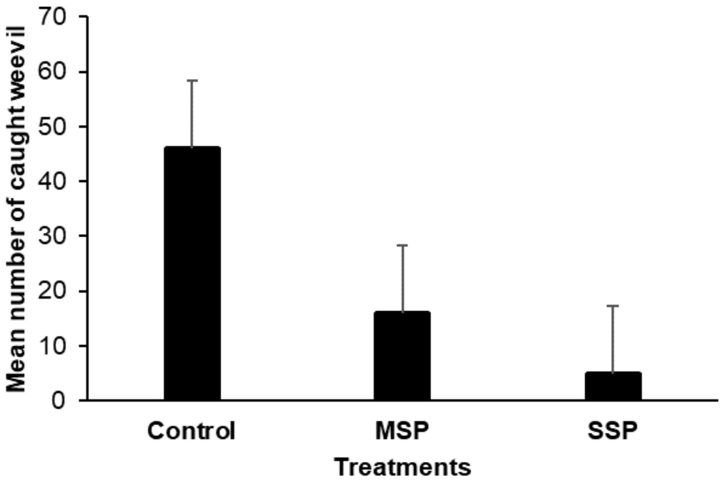


**Figure 5.** Pine weevil caught at control sites, multiple stump pile (MSP), and single stump pile (SSP) sites.

Article I also showed that stump harvesting can reduce the damage done to seedlings by pine weevils (Figure 6). Although multiple stump piles attracted more weevils compared to single stump pile, feeding damage was more intensive in the control than in the stump removal area. This was probably influenced by the effect of the different stump harvesting working phases that disturbed the humus-rich soil, which would have been favourable for pine weevil movement and feeding (Björklund et al. 2003). Article I also reported that seedling damage in single stump pile site was lower than that in multiple stump pile site. This probably occurred because of how the operation of excavators and forwarders affected the humus and exposed mineral-rich soil during the stump harvesting process. Mounds of mineral-rich soil can reduce the damage that pine weevils cause to seedlings (Luoranen et al. 2017). Stump removal can therefore be combined effectively with mounding (Saarinen 2006).

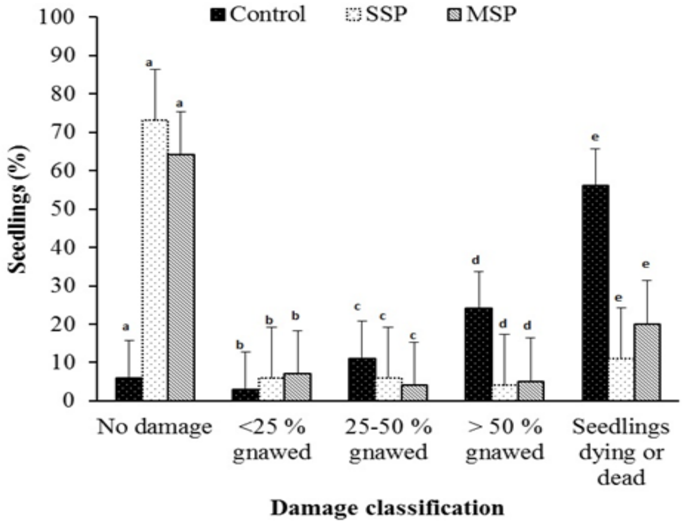


**Figure 6**. Damage to seedlings cause by pine weevils (*Hylobius abietis*) in control, multiple stump pile (MSP), and single stump pile (SSP) sites. The letters above the error bars indicate significant differences in damage classification within the relevant group.

*3.1.2 Effect of stump harvesting timing on weevil activity*

Article II showed that stump removal significantly reduced pine weevil breeding material. It also revealed that large numbers of pine weevil larvae still occur in stump removal areas, which may mature later and has ability to damage seedlings (Figure 7).

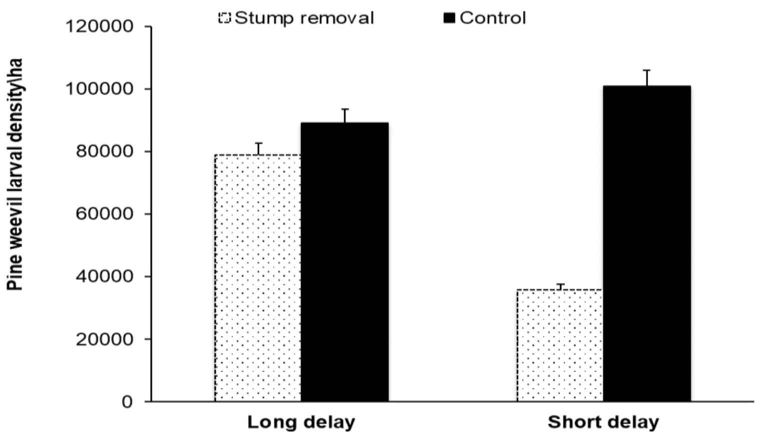


**Figure 7.** Estimated marginal means (±S.E.) of Pine weevil larval density in stump removal and control sites with long delay and short delay time lag difference between logging and stump extraction

In practice, it is not possible to remove all roots and stumps from clear-cut areas. The larvae remaining in the stumps and roots are likely to emerge and may cause seedling damage and newly hatched pine weevils may stay in the area for some years (von Sydow 1997; Örlander et al. 1997).

However, Article II revealed that current Finnish stump removal practice is a significantly effective operation for reducing 48% of the population of pine weevil larvae if done shortly after logging instead of in a delayed manner. This was indicated by lower number of roots containing pine weevils and lower root surface area gnawed by larvae (Figure 8). At sites where stump extraction was conducted shortly after the logging occurred, the species probably had less time to colonise the stumps and roots before these were extracted. In addition, short-delay conditions might have reduced the level of volatile compounds emitted, thereby attracting fewer pine weevils to the site. Extracted stumps should therefore not be kept within the clear-cut area as weevils are attracted to fresh stumps.

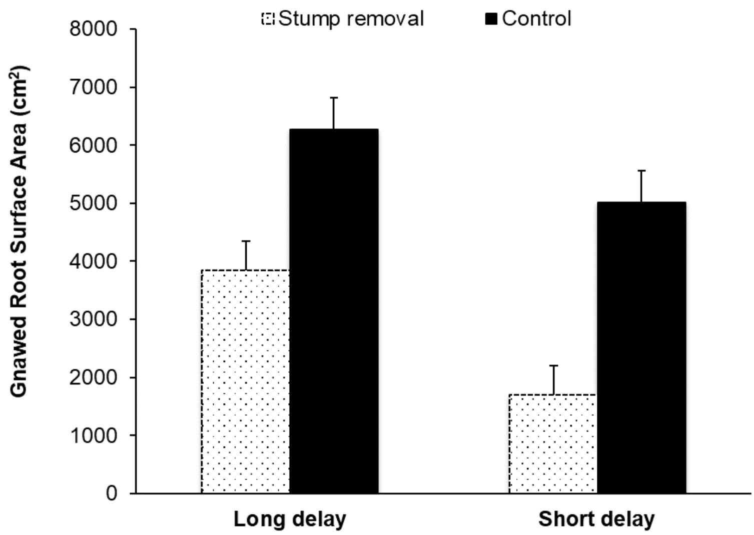


**Figure 8.** Estimated marginal means (±S.E.) of gnawed root surface area by Pine weevil and *Hylastes* spp. larvae in control and stump-removal sites with short- and long-delay stump extraction time.

### *3.1.3 Stump extraction in pine weevil damage control*

Stump harvesting may reduce pine weevil feeding damage, if stump removal is carried out before pine weevil colonisation. Otherwise, this pest may colonise in the stump roots and has opportunity to swarming after the planting of seedlings. It was also found, recently, that pine weevil feeding damage is more frequent if seedlings are planted in May, when a new pine weevil generation migrates to a site, than if planting is done in June (Nordlander et al. 2017). Pine weevil migration and swarming times have an influence on their feeding habits. However, a four-year-old root is also suitable for colonisation by pine weevils (Nordenhem, 1989), and *Hylastes* species can cause damage to seedlings for up to six years (Lindelöw, 1992). In the UK, stump removal is less effective at reducing pine weevil seedling damage after the egg-laying period (Heritage and Moore 2001)

In Finland, it takes more than two years before pine weevils in North Karelia develop from egg to adults. This long development time means that if stump piles are not preserved along roadsides in the forest for longer than two years, the larvae within them are trapped and transported away from the forest. However, the proportion of weevils trapped this way is too small to prevent damage to seedlings using this method.

It is thus necessary to manage stump harvesting techniques and systems in cooperation with experts with the relevant knowledge of forest health and ecosystems. Article I revealed that reducing pine weevil damage to seedlings via stump harvesting may be partially successful. Multiple stump piles and long delays in stump harvesting management systems undermine the reduction of pine weevil breeding material and emergent weevil population. Forest managers therefore have to make site-specific decisions and reconsider the expense of stump extraction given this ecological and economic knowledge. Moreover, stakeholders in stump harvesting processes should have adequate ecological and socio-economic information on stump harvesting for bioenergy production.

## 3.2. Stakeholder perception of stump harvesting

Apart from stump harvesting management to reduce seedling damage by pine weevil, there are other theoretical benefits to this practice, including additional income and improved site preparation for forest owners and additional energy sources for commercial bioenergy production. Article III reveals that stakeholders are aware and have adequate knowledge of stump harvesting. Most of the respondents of SILVA fair are forest owners and have a forestry background. Stump harvesting is also practising in North Karelia and for Finnish stakeholders SILVA fair is an important platform, as well as visiting respondents with forestry background an important source of information.

It also showed that highly knowledgeable people tended to support stump removal as a method to improve site preparation and reduce damage to seedlings from pine weevil feeding (Table 4). The findings reported in Articles I and II supported the opinion of stakeholders on the latter issue; however, they also expressed concern about the negative impacts of stump harvesting on biodiversity, site productivity, and soil properties. Article III reported that almost 53% of respondents indicated that stump harvesting could not provide additional income and could not be profitable, even though it has been shown that stump harvesting can in fact provide extra income to forest owners (Mabbett 2009). In addition, stump-excavation costs can be minimised via revenues from stump harvesting (Walmsley and Godbold 2009). This could be supported by tax revenues and subsidies meant to support the replacement of fossil fuels with the wood-based biofuel sector (Khanam et al. 2016), in which cost is a significant factor (Adams et al. 2011).

According to Article III, stakeholders were interested in learning more about stump harvesting (Figure 9). Most respondents agreed that stumps are future bioenergy sources. However, highly knowledgeable people had critical views on this because, for example, of the variation in the quality of stump wood (Laurila and Lauhanen 2010). This is because stumps excavated in stump harvesting management are usually supposed to be piled near the clear-cut area for natural cleaning and drying that improves its quality. In practise, stumps are piled at site for the first time for drying for some weeks and are transported later along to roadside for longer drying period. When stumps are moved and piled twice, loose sand and stones will dropped away, which improves quality of the stumps as fuel. This strategy may also decrease pine weevil incidence, as indicated in Article I. The excavated stumps can also be split into smaller pieces to minimise impurities and moisture content and to accelerate the drying process (Anerud and Jirjis 2011).

Thus, stump harvesting is a complex issue in Finland. The Finnish consulting service TAPIO suggested guidelines for stump harvesting (Koistinen 2016), but Article III indicates that stakeholders nonetheless remained doubtful about the practice. Stump harvesting changes the aesthetic value of forests, which displeased the stakeholders, and their opinion gradually changed as the seedlings begin to grow (Persson et al. 2017). Article III revealed that the respondents accepted stump harvesting more as a forest management than as a source of extra income. There has been much discussion on stump harvesting for bioenergy production, but a study stakeholder acceptance of stump harvesting in Finland is also necessary to understand the present situation.

**Table 4**. Percentage of respondents' perceptions of some benefits of stump harvesting (N=166)

| Statement | Accepted (%) | No opinion (%) | Rejected (%) |
|---|---|---|---|
| 1. Stump harvesting increases wood fuel production in the EU | 53 | 23 | 24 |
| 2. Stump harvesting is vital for forest owners from the revenue point of view | 24 | 23 | 53 |
| 3. Stump harvesting has ability to improve site preparation | 73 | 10 | 17 |
| 4. Stump removal can reduce pine weevil feeding damage to seedlings | 62 | 26 | 12 |

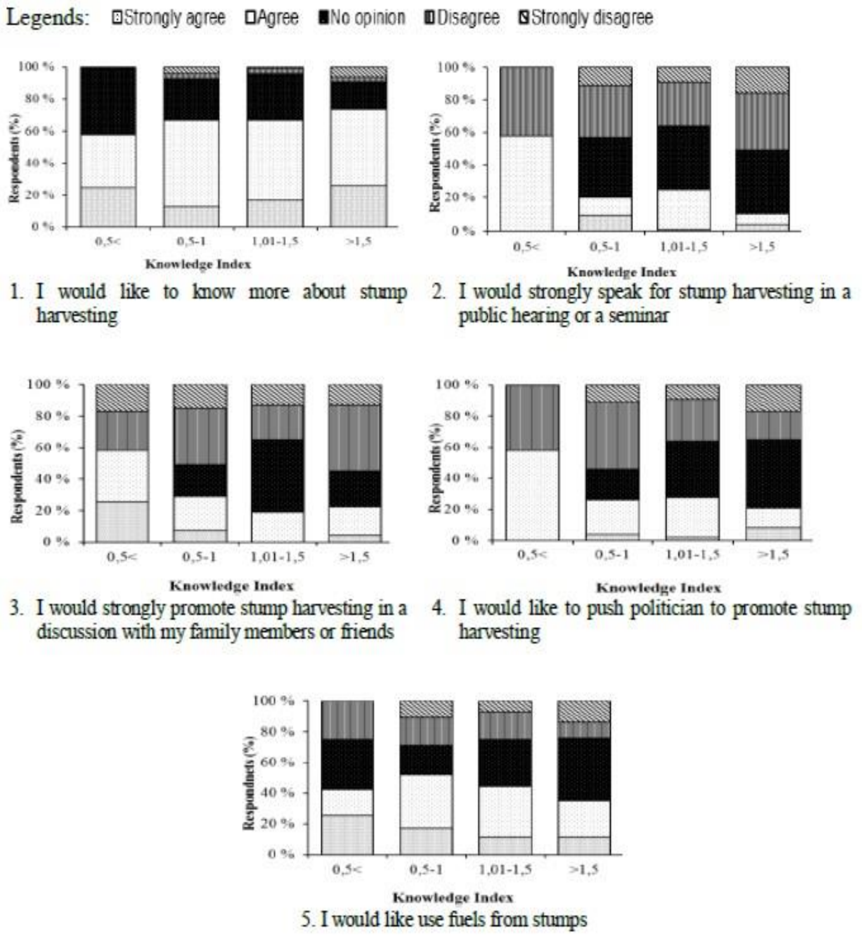


**Figure 9**. Distribution of respondents attitudes statements on the basis of knowledge index towards stump harvesting (N=166).

### 3.3. Stakeholder acceptance of stump harvesting

Finland can obtain bioenergy from forest resources and develop associated bioenergy resources such as stump wood. Companies working with forest products are interested in continuing stump harvesting fort this purpose. However, environmental non-governmental organisations, such as the World Wide Fund for Nature, claim that stump harvesting is not a sustainable practice (WWF 2013). Therefore, it is necessary to scientifically verify the benefits and environmental impacts of stump harvesting to the public. Article IV indicates that an increasing number of studies have been conducted recently and have produced contradictory results regarding stump harvesting. In addition, the media has portrayed the impact of stump harvesting negatively over the past two decades. Under these circumstances, public acceptance of stump harvesting is vital for the development of stump harvesting systems. For example, timber felling is acceptable because it is regulated by a certification system, and sustainable forest management is generally accepted by society. In contrast, there is little public involvement in stump extraction for bioenergy production. However, the concept of a bioeconomy has been discussed extensively over the past decades, with a focus on obtaining bioenergy from forest resources, particularly because the EU has become increasingly interested in obtaining energy from renewable sources. Increasing public acceptance of the concept of obtaining energy for the bioenergy sector from extracted stumps should therefore be given more attention.

The results in Article IV showed that SPA and MA jointly enjoyed higher priority regarding stump harvesting than individual public acceptance dimensions did (Table 5). In recent years, the consumption of energy from stump wood has decreased (Luke statistic 2017). This may be due to poor investment in technological developments and decreased public interest in this field. Public acceptance and satisfaction are vital in the socio-political and community contexts for developing stump harvesting systems. As a raw material, stump wood fuel faces more challenges than does fossil fuel energy production, and there is less research interest to improve associated technology and public awareness. Article IV showed that forestry and farm workers, whose livelihoods depend on forests, are more interested in stump harvesting (which involves reduced pine weevil damage), although higher level administrators appeared to think more critically about the issue. Different stakeholders focused on scientific data or media exposure to form their perspective (Kangas et al. 2018). In terms of stump harvesting, diverse public participation is necessary for the development of a bioeconomy.

A strength, weakness, opportunity, and threat (SWOT) analysis was therefore carried out, based on the findings of this study (Table 6), to determine the competitiveness of stump harvesting. Most threats are from contradictory research results. In terms of forest regeneration, compared to only stump removal, seedling survival of Scots pine and Norway spruce was higher in both slash and stump removal processes (Karlsson and Tamminen 2013), but the opposite was found by Saksa (2013) and Egnell (2016). Carbon balance studies have shown that 10 years of harvesting resulted in declining soil carbon stocks (Hope 2007). However, after 8–13 and 32–39 years, there were no substantial carbon differences between the stumps removed or traditional stands (Hyvönen et al. 2016; Jurevics et al. 2016). From an economic perspective, Saarinen (2006) indicated that stump harvesting was a source of fuel and income for forest owners, but Article III showed that forest owners were less interested in the financial benefit but favoured site preparation by stump harvesting. In addition, media and environmental non-governmental organisations viewed stump harvesting in an unfavourable light because of biodiversity concerns (Kangas et al. 2018).

**Table 5**. Distributions of respondents' answers related to opinion statements regarding stump harvesting in terms of social acceptance categories (N=166)

| Dimensions | Accepted (%) | No opinion (%) | Rejected (%) |
|---|---|---|---|
| SPA | 28 | 33 | 39 |
| MA | 50 | 19 | 31 |
| SPA+CA | 24 | 34 | 42 |
| SPA+MA | 69 | 21 | 11 |
| SPA+CA+MA | 43 | 30 | 27 |

SPA: socio-political acceptance; MA: market acceptance; CA: community acceptance

**Table 6**. SWOT analysis based on the findings of Articles I–IV

| Strengths | Weaknesses |
|---|---|
| 1. Stump harvesting has the ability to reduce pine weevil larvae and their breeding resources (I, II)<br>2. People accepted that stump harvesting can reduce pine weevil damage and increase wood fuel production (III) | 1. People do not agree that stump harvesting will provide greater revenue. (III)<br>2. People believe that stump harvesting leads to soil damage and nutrient loss (III)<br>3. Stump harvesting by itself is not an effective protection method for controlling damage by pine weevils (II) |
| **Opportunities** | **Threats** |
| 1. People want to use stump wood for future energy (III)<br>2. People are interested in obtaining more information regarding stump harvesting (III) | 1. People have been confused about stump harvesting due to numerous contradictory research results (IV)<br>2. People do not want to promote stump harvesting (III) |

Stakeholders agreed that stump harvesting leads to soil damage and nutrient loss, which are its weaknesses. Stakeholder opinion is also reflected by those in the scientific community who feel the same way (Kaarakka et al. 2018). The weaknesses and threats of stump harvesting, as identified by the SWOT analysis, confuse public opinion about stump harvesting. However, despite these, stump harvesting also has strengths such as providing environmental and economic opportunities. Bioenergy fuels provided by forests may contribute to a Finnish bioeconomy, and stakeholders are interested in knowing more on stump harvesting and using stump wood for energy production in the future. The demand for forest-based bioenergy resources is also likely to increase as Finland moves towards a bioeconomy. Because people are cognisant of the high fuel value of stumps, the focus on stump harvesting is likely to increase with developments in technology that would enable high productivity and less soil disturbance in stump utilization.

The European Commission has set a goal of developing a reasonable, resource-efficient and low-carbon economy by 2050 (COM 2011). The first bioeconomy strategy was established by the EU in 2012 (EC Bioeconomy 2017). Finland followed suit and established such a strategy in 2014. A bioeconomy and 'clean solutions' form part of the Finnish government's vision for 2025 (Government Publication 2016). The Finnish National Forest strategy 2025 vison relies on sustainable forest management. According to the Finnish government, '[b]ioeconomy means an economy that depends on renewable natural resources to produce energy, food, bioproducts, and services'. The government believes that a bioeconomy will sustainably decrease the use of fossil fuel resources in energy production, protect biodiversity, create new jobs, and promote economic growth. Finland aims to be a pioneer in the circular economy (SITRA 2017). In 2016, the bioeconomy accounted for EUR 64.4 billion or 16% of the Finnish national economy (Luke Finnish Bioeconomy 2018). Forest-based bioeconomics played a major role in this and is expected to raise another EUR 100 billion in Finland by 2025 (Bioeconomy 2014). The use of stump wood in CHP plants may therefore increase due to recent bioeconomic policy that encourages more intensive wood harvesting. Stump harvesting for bioenergy production is nonetheless a complex policy matter and requires scientific attention in light of climate change.

# 4. CONCLUSION, RECOMMENDATIONS, AND DIRECTIONS FOR FUTURE RESEARCH

As Finland moves towards a greater bioeconomy, the findings of this dissertation will contribute to the development of stump harvesting. This study showed that to achieve sustainable stump management, both ecological and social factors should be considered, as they affect the market development of stump harvesting. This was the first study to provide a comprehensive explanation of the relationship between stump harvesting and pine weevil ecology combined with stakeholder acceptance of stump harvesting. In addition, this study attempted to explain the social, economic, and environmental issues surrounding commercial stump harvesting.

Practical field work allowed the study of pine weevil incidence, feeding, and seedling damage in a Finnish forest managed using a stump harvesting system. The timing of stump harvesting and arrangement of stump piles were found to significantly affect weevil incidence. Immediate arrangement of extracted stumps in clear-cut areas and large stump piles not too close to clear-cut areas may reduce pine weevil feeding damage to some extent. Removing only fresh stumps from clear-cut areas does not necessarily solve the weevil damage problem, because of pine weevil biological and dispersal behaviour. Moreover, the complete removal of stumps and roots is ecologically complex and expensive.

This dissertation demonstrated that commercial stump harvesting is partially achievable if it can be managed according to scientific principles, data on best practices can be updated accordingly, and attention is given to stakeholder perceptions. This dissertation also suggests that stump harvesting can be an element of forest management and that this depends on stakeholder acceptance. Its findings can therefore contribute towards future revisions of guidelines for stump harvesting. However, this dissertation only illuminates one future pathway for the development of stump harvesting. Interactions between ecological and social factors need to be studied further to fully understand the development of the complex process of stump harvesting. Future research should focus on policy implications of stump harvesting based on updated technological guidelines and considering stakeholder perception. Therefore, more inter- and multi-disciplinary research is needed on stump harvesting.

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# APPENDIX

## Questionnaire for opinion towards stump harvesting

Following questionnaire is designed for compilation of scientific research, which is about public opinion towards stump harvesting. Questionnaire responses and personal information is not used to influence someone, and will be published only scientifically. Your answers are very important for us. If you have any questions regarding the completion of this questionnaire please contact abul.rahman@uef.fi

### A. Profile of the respondent

1. Are you forest owner?
☐ Yes ☐ No

If yes then how many hectares of forest you have? ……............. ha

2. Did you study any forestry course?
☐ Yes ☐ No

3. Social group/background
*Please select from the following options (by marking the right box if applicable).*

☐ Higher administrative or clerical employees and employers comparable with them, and persons with academic degrees

☐ Lower administrative or clerical employees and employers comparable with them

☐ Skilled or specialized workers

☐ Farm and forestry workers

☐ Students, pupils

☐ Social group unknown

4. Age: 5. Gender: M ☐ F ☐

### B. Respondent’s knowledge about stump harvesting

6. Stump harvesting yields typically in Northern Europe
*Please select only one answer from the following options.*

☐ Less than 15 % of the above ground harvested biomass

☐ 15-30 % of the above ground harvested biomass

☐ More than 30 % of the above ground harvested biomass

7. Stump harvesting take place in:
*Please select only one answer from the following options.*

☐ Germany

☐ Italy

☐ Finland

☐ Norway

8. For combustion stumps will be
*Please select only one answer from the following options.*

☐ Chipped

☐ Crushed

☐ Splitted

9. Energy content of stumps is:
*Please select only one answer from the following options.*

☐ 5% lower than forest residues

☐ Similar as forest residues

☐ 5% higher than forest residues

10. Which one below of forest biomass sources is the most important in Northern Europe?
*Please select only one answer from the following options.*

☐ Stumps

☐ Slash and branches

☐ Wood from thinning

☐ Pulp wood

☐ Saw wood logs

11. How do you rate your knowledge about stump harvesting?

☐ Very poor ☐ Poor ☐ Do not know ☐ Good ☐ Very good

## C. Respondents opinion towards stump harvesting

12. Please indicate whether you are agreeing with the following statements? *Please just select only one option of the each statement.*

| **Statement** | *Strongly agree* | *Agree* | *No opinion* | *Disagree* | *Strongly Disagree* |
|---|---|---|---|---|---|
| Stump harvesting remarkably increases production of woodfuel in EU | | | | | |
| Stump harvesting is important from the revenue point of view for forest owners | | | | | |
| Stump harvesting can improve site preparation | | | | | |
| Stump removal can reduce root rot diseases | | | | | |
| Stump removal can reduce pine weevil insect damage to seedlings | | | | | |
| After stump harvesting, soil nutrient content will decrease | | | | | |
| After stump harvesting soil pH level will decrease | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Stump harvesting leads to remarkable soil carbon emissions | | | | | |
| Stump harvesting leads to further disruption of the physical structure of the soil | | | | | |
| Stump harvesting has an impact on water catchments | | | | | |
| Stump harvesting has harmful effect on forest biodiversity | | | | | |
| Stump harvesting has effect on future site productivity | | | | | |

**D. Respondent's attitudes towards stump harvesting**

13. Please indicate whether you are agreeing with the following statements? *Please just select only one option of the each statement.*

| **Statement** | *Strongly agree* | *Agree* | *No opinion* | *Disagree* | *Strongly Disagree* |
|---|---|---|---|---|---|
| I would like to know more about stump harvesting | | | | | |
| I would strongly speak for stump harvesting in a public hearing or a seminar | | | | | |
| I would strongly | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| promote stump harvesting in a discussion with my family members or friends | | | | | |
| I would like to push politician to promote stump harvesting | | | | | |
| I would like use fuels from stumps | | | | | |
| Only the government should allocate more resources for the development of stump harvesting technologies | | | | | |

**E. Additional comments if you want to give**

Comments, observations and suggestions about stump harvesting (optional):
Thank You for Your help!