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Interest in vegetatively propagated Norway spruce materials – a survey among Finnish forest owners and professionals

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Highlights

- Survey among forest owners and professionals' perceptions towards tree breeding and vegetative propagation yielded over 3000 responses.
- Most valued features in reforestation material were: improved resilience in changing climate, improved pest and pathogen resistance, and securing the species' gene pool.
- Majority of respondents accepted reforestation with vegetatively propagated material to some extent; Willingness to pay for improved features was indicated.

Abstract

Forests and forestry will encounter several changes of unknown magnitude within the coming decades. In the Nordic, long rotations complicate any anticipation to the upcoming changes. Tree breeding can contribute to coping with these changes. The time span of implementing breeding results in practice may be shortened through vegetative propagation. Introducing vegetative propagation to forest regeneration may phase several challenges before adopted by the industry, some of which are related to perceptions about new technology. Firstly, private forest owners are in a key role in implementing the technology in practice; although they do not represent the overall public, they are the decision makers in their own estates regarding forestry and forest regeneration. Secondly, the professionals related to the production of forest regeneration material and plants from forest species are in a key role when it comes to practically introducing the new technology to the forest owners. In this survey, perceptions of forest owners and professionals towards tree breeding and vegetative propagation were investigated. Additionally, the respondents were asked which traits they considered important to be improved by breeding, and their willingness to pay for these improved traits. The respondents valued the most: improved pest and pathogen resistance, improved resilience of forest in changing climate, and securing the species' gene pool. Responses indicated that forest owners would be willing to pay more for the improved traits in forest regeneration material. The current novel study provides a foundation to concern public awareness regarding tree breeding and vegetative propagation in the future.

Keywords *Picea abies*; desired traits; intention of adoption; somatic embryogenesis; willingness to pay
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1 Introduction

The future will force us to face challenges caused by climate change while the demand for bio-based raw materials is expected to increase (Pop et al. 2014; Ruotsalainen 2014; Börjesson et al. 2017; Jansson et al. 2017). Rotations of several decades in Nordic forestry complicate preparing for such upcoming challenges (Ruotsalainen 2014). Tree breeding can contribute to solving these issues by producing genetically improved planting stock conventionally carried out through seed orchards (White et al. 2007; Ruotsalainen 2014).

Though reliable and scalable, utilising genetic gain in growing stock via seed orchards can be challenging with some species, e.g., Norway spruce (*Picea abies* [L.] H. Karst.) which is known to have irregular flowering causing fluctuating seed yields (Haapanen et al. 2017; Jansson et al. 2013). Occasional shortage of improved seed could be eased by producing planting stock via vegetative propagation, which would also enable more efficient utilisation of breeding results (Högberg et al. 1998; Haapanen and Mikola 2008; Varis 2018).

Vegetative propagation allows the exploitation of non-additive genetic features directly in planting stock (Díaz-Sala 2016). Several methods of vegetative propagation are available, of which somatic embryogenesis (SE) based on tissue culture has been considered the most promising for industrial application for conifers (Lelu-Walter et al. 2013). The possibility to combine SE with reliable and practical cryopreservation techniques and store juvenile propagation material for decades, makes SE even more attractive to Nordic conifers (Varis et al. 2017). Generally, SE in conifers is performed by using seed embryos as explants (Chalupa 1985; Hakman et al. 1985; Nagmani and Bonga 1985). Recently, improvements of initiating Norway spruce cultures from primordial shoots of juvenile somatic trees have been reported, although further research is still needed for the initiation of SE from adult trees (Varis et al. 2018).

Tikkinen et al. (2019) described a development of SE-pipeline covering also the registration of SE material for forest regeneration in Finland following EU and national legislation, and commercial pilots where SE derived forest regeneration material was produced for customers. Currently, somatic plants (emblings) are produced manually in Finland, although efforts have been made to automate and scale up Norway spruce SE (Egertsdotter et al. 2019; Välimäki et al. 2020).

In the early stages of SE commercialisation, it is important to take into account not only the customers' interest in the novel product but also the economic aspects such as cost efficiency and customers' willingness to pay for, e.g., improved growth or tailored quality characteristics. In addition, the societal acceptance of SE is essential, as reported by Rosvall et al. (2019a, 2019b), with the fact that whenever the use of vegetative propagation in forestry is considered, concern about genetic diversity arises and needs to be taken into account.

The aim of the present study was to examine interest in vegetatively propagated Norway spruce materials, i.e., emblings, among Finnish forest plant producers and end users. Among the end users, forest owners represent the largest group, but also producers of Christmas trees and ornamental trees were included in the survey. The questions in this study covered desired traits in vegetatively propagated spruce materials, and the respondent's willingness to pay for improved plant material. Furthermore, the benefits and risks of using vegetative propagation were investigated in the study questions together with the acceptability of vegetatively propagated materials.

2 Material and methods

2.1 Data

The survey targeted forest owners, forest regeneration material producers (seed and seedling producers), producers of Christmas trees and ornamental trees, and other nurseries which have collaborated with Natural Resources Institute Finland (Luke) in previous research projects. The survey was distributed among members of Finnish forest plant producers (Suomen metsätaimituottajat ry) and the Christmas tree society (Joulupuuseura ry), which are both registered associations, and to over 200 members of the estimated 500 Christmas tree producers in Finland (Joulupuuseura 2020). Private forest owners with at least 30.5 hectares forest land (the mean forest property size in Finland in 2018) received the questionnaire via email. The contact information for these 65 018 forest owners was obtained from the Finnish Forest Centre (Metsäkeskus).

2.2 Survey design

Respondents were recruited through email invitation with a link to the tailored survey between May and June 2019. The invitations were sent to different groups of respondents either directly or through collaborators (Finnish forest plant producers [Suomen metsätaimituottajat ry] and the Christmas tree society [Joulupuuseura ry]). As a background question, the nature of forestry entrepreneurship together with affiliation in forestry organisations was inquired from the respondents. Additionally, professional experience and career length, mean approximate number of seedlings or trees handled annually, and previous experience regarding vegetative propagation were inquired.

2.2.1 Questions asked: background and study questions

The survey started with a short introduction to vegetative propagation, explaining the essential features. As one of the vegetative propagation techniques, Somatic embryogenesis was also described together with a reference to Finnish legislation related to vegetatively propagated forest regeneration materials, as well as an explanation of genetic diversity measures (Supplementary file S1, available at https://doi.org/10.14214/sf.10506).

The survey was tailored depending on the respondent group, and respondents classified themselves within the given alternatives. Those questions targeting respondents who classified themselves as forest owners included, e.g., importance of resilience, resistance traits, high growth rate, and high timber quality for their choice of plant material. In the case of producers of ornamental trees and Christmas trees, the significance of phenotypic characteristics such as needle colour and growth habit, as well as the need for repeated shoot excision to shape crown form was asked. Overall, special traits to be included in the survey were chosen so that SE material expressing them either already exists or seems realistic to produce in the near future based on current knowledge.

Willingness to pay was measured as an additional price for a high breeding value in different ambivalent categories. Expectations of the future developments of the new technology including the expected benefits, risks and acceptance of the vegetatively propagated plant material were also explored. In addition, an acceptable proportion of forest regeneration material that could be vegetatively propagated was requested, taking into account genetic diversity issues that were first shortly introduced to respondents (Suppl. file S1).

2.3 Estimation of willingness to pay

For measuring willingness to pay (WTP) for quality characteristics a stated preference method, a contingent valuation, was used. Two WTP question formats were used: firstly, an open-ended WTP question (€ per plant), and secondly, a multiple bounded dichotomous choice (MBDC) format that allows the respondent to express their ambivalence. In that question format, respondents were given an identical set of bids and for each bid they had five response categories to choose from ‘Definitely would not accept’, ‘Possibly would accept’, ‘Definitely would accept’, and ‘Cannot say’.

Respondents’ mean WTP can be estimated non-parametrically, without assuming a utility function or distribution of an error term. In such cases, WTP is estimated using bids (i.e., a price increase of 25%, 50%, 75%, or 100%) and point estimations of WTP probabilities. According to economic theory, when an offered bid (price increase or cost) increases, the proportion of observed “no” responses to each bid should increase: genuinely monotonic distribution functions. Sometimes, this is not true due to randomness, in which case the Turnbull distribution-free estimator can be applied (Turnbull 1976; Haab and McConnell 2002).

In the non-parametric estimation of a dichotomic WTP question, the relative proportion of “no” responses are calculated for each bid, a point estimator for the WTP function is made for each bid t_i , and the relative proportion of “no” responses F_j is calculated as follows:

$$F_j = \frac{N_j}{T_j}\ ,\ j = 0 \rightarrow \mathrm{J}\ , \tag{1}$$

where N_j is the proportion of “no” responses of the combined total, and T_j is the proportion of all “yes” and “no” responses.

WTP is calculated from a monotonic WTP curve by dividing WTP in subranges $\{0 - t_1, t_1 - t_2, \dots, t_{M*} - U\}$. To calculate the lower bound estimate (LB) of WTP, WTPLB (indicates that the accumulation of the probability mass is calculated only at the lower end bound of the subrange yielding conservative estimates), $F(0) = 0$ (cumulative density function at the lower bound of WTP), and the upper bound for the WTP must be determined. By using these subranges, WTP can be calculated with the following formula:

$$E_{LB}(WTP) = \sum_{j=0}^{M*} t_j \times f_{j+1}^{*}\ , \tag{2}$$

where t_j is offered extra cost and $M*$ is the number of bids.

2.4 Models for technological acceptance

The survey also explored how a respondent would accept these forthcoming technologies. Currently in the literature, four highly significant theoretical models dealing with the acceptance of technological innovations exist: (1) the Technology Acceptance Model (TAM), developed by Davis (1989), (2) the Theory of Planned Behaviour (TPB) by Ajzen (1991), (3) the extended Ajzen’s model by Taylor and Todd (1995), and (4) the Unified Theory of Acceptance and Use of Technology (UTAUT) model constructed by Venkatesh et al. (1996). In this study, the modified UTAUT model was applied to measure innovation acceptance for vegetative propagation in the forest sector. A similar adoption model was tested in an agricultural sector in Naspetti et al. (2017) (Table 1).

Table 1. Theoretical constructs of technological acceptance of vegetatively propagated material. (Construct, Definition, Code and Statement wording) applied in the analysis: adapted from previous study of Naspetti et al. (2017) and statements modified to the vegetative propagation.

Construct	Definition	Code	Statement wording
Attitude Towards Use	A respondent's positive or negative feeling associated with vegetative propagation	AA1	I think that the adoption of vegetative propagation would be acceptable for my company or my forest.
		AA2-	All things considered, I think that adopting vegetative propagation is not a good idea.*
		AA3	I think that the adoption of a vegetative reproduction would be wise.
Perceived Ease of Use	The extent to which a respondent believes that using a vegetative propagation would be effortless	PEOU1-	I think that the adoption of vegetative propagation would require substantial restructuring of supply chain activities and processes.*
		PEOU2	I think that the adoption of the vegetative propagation would not demand much effort.
		PEOU3-	All things considered, I think that the adoption of the vegetative propagation would require a large effort in training and advice.*
Perceived Usefulness	The extent to which a respondent believes that using a particular production strategy will enhance his/her company performance or industry	PU1	I think that the adoption of vegetative propagation would improve the profitability of a company.
		PU2-	All things considered, I think that the adoption of vegetative propagation would not prove useful for my company.*
		PU3	I think that the adoption of vegetative propagation would be advantageous for the industry.
		PU4-	I think that the adoption vegetative propagation would be too costly for the industry.*
		PU5	I think that the adoption of vegetative propagation would increase the effectiveness of the industry.
Subjective Norm	A personal perception of relevant opinions on whether to adopt the vegetative propagation	SN1	I think that leading companies in the industry would favour the adoption of the vegetative propagation.
		SN2	I think that most people who are important to my company would favour the adoption of vegetative propagation.
		SN3	If it were widespread, I think that my company would favour the adoption of vegetative propagation.
Intention to Adopt	An intention to adopt the vegetative propagation	IA1-	All things considered, my company is hardly to adopt vegetative propagation in the near future.*
		IA2	All things considered, my company will adopt vegetative propagation in coming years.

* Denotes a reverse-scored statement.

For analysing the attitudes and intention to adopt new technologies, a tailored model for the study was applied and the analysis was conducted by means of the factor analysis combined with reliability analysis (Cronbach's Alpha). All the variables were measured using a 5-point Likert scale from (1) 'Strongly disagree' to (5) Strongly agree'. Six out of the 16 statements had reverse coding indicating a negative attitude or intention.

3 Results

3.1 Background of respondents

3.1.1. Target groups

The respondents were categorised into different target groups according to their own estimation. From the indicated options (Table 2), the target group 'Private forest owner/ Responsible for private forest' was the largest and most heterogeneous of the respondent groups (89.6% of respondents overall). Of the 2918 respondents within this group who identified themselves belonging to

Table 2. Target groups of respondents in the survey of perceptions towards tree breeding and vegetative propagation, number of respondents identifying themselves in each target group, proportion of respondents in each target group overall, experience regarding vegetative propagation presented, and the interest towards possibilities to improve certain traits in propagation material, with the scale from one (not at all important) to four (highly important); mean values presented with a standard error of the mean. Answers in each group with a mean value with ≥ 3.4 in bold and underlined.

	Private forest owner / responsible for private forests	Private forest organisation	Producers of Christmas trees	Public forest organisation	Responsible for public forests (public sector)	Forest plant producers	Seed producers	Producers of ornamental trees	Other	All
Number of respondents	2833	105	44	38	26	20	15	11	71	3163
Share of respondents, %	89.6	3.3	1.4	1.2	0.8	0.6	0.5	0.3	2.2	100.0
Experience of vegetative propagation, % (if yes)	23	41	39	31	46	35	27	72	47	
Production of plants with known characteristics	3.1 (±0.0)	3.2 (±0.1)	3.2 (±0.1)	3.2 (±0.1)	3.1 (±0.2)	3.3 (±0.2)	3.2 (±0.2)	3.2 (±0.2)	3.0 (±0.1)	3.1 (±0.0)
Enabling storage of regenerable cell lines for decades	2.9 (±0.0)	3.0 (±0.1)	3.0 (±0.2)	3.1 (±0.1)	2.9 (±0.2)	3.0 (±0.2)	2.9 (±0.2)	**3.6 (±0.2)**	2.8 (±0.1)	2.9 (±0.0)
Produce tailor-made wood as raw material for industries	2.9 (±0.0)	3.0 (±0.1)	3.3 (±0.1)	2.7 (±0.1)	2.8 (±0.2)	2.9 (±0.2)	2.8 (±0.1)	2.8 (±0.2)	3.1 (±0.1)	2.9 (±0.0)
Produce desired secondary compounds	3.0 (±0.0)	3.1 (±0.1)	3.1 (±0.1)	2.9 (±0.1)	3.0 (±0.2)	3.0 (±0.2)	3.3 (±0.2)	3.1 (±0.3)	3.0 (±0.1)	3.0 (±0.0)
Increase growth remarkably	3.2 (±0.0)	3.2 (±0.1)	**3.4 (±0.1)**	3.0 (±0.1)	**3.4 (±0.1)**	3.2 (±0.2)	**3.4 (±0.1)**	3.3 (±0.2)	**3.4 (±0.1)**	3.2 (±0.0)
Shorten rotation time	3.1 (±0.0)	2.9 (±0.1)	3.3 (±0.2)	2.9 (±0.2)	**3.4 (±0.1)**	2.9 (±0.3)	3.3 (±0.2)	2.9 (±0.3)	3.2 (±0.1)	3.1 (±0.0)
Improve wood quality	3.3 (±0.0)	3.3 (±0.1)	3.3 (±0.1)	3.1 (±0.1)	**3.7 (±0.1)**	3.2 (±0.2)	3.2 (±0.2)	3.3 (±0.2)	**3.4 (±0.1)**	3.3 (±0.0)
Improve resilience of forests in changing climate	**3.4 (±0.0)**	**3.4 (±0.1)**	**3.5 (±0.1)**	3.1 (±0.1)	3.3 (±0.2)	3.3 (±0.2)	**3.4 (±0.2)**	3.1 (±0.3)	**3.4 (±0.1)**	**3.4 (±0.0)**
Securing species' gene pool (biotic or abiotic threats)	**3.4 (±0.0)**	**3.4 (±0.1)**	**3.5 (±0.1)**	3.3 (±0.1)	**3.6 (±0.1)**	**3.4 (±0.2)**	**3.5 (±0.2)**	**3.7 (±0.1)**	**3.5 (±0.1)**	**3.4 (±0.0)**
Improve decay resistance of trees/ wood	3.2 (±0.0)	3.2 (±0.1)	3.3 (±0.2)	3.0 (±0.1)	**3.4 (±0.1)**	3.1 (±0.2)	3.0 (±0.2)	3.2 (±0.2)	3.1 (±0.1)	3.2 (±0.0)
Improve pest resistance of trees	**3.4 (±0.0)**	**3.5 (±0.1)**	3.3 (±0.2)	3.3 (±0.1)	3.3 (±0.2)	3.3 (±0.2)	**3.5 (±0.1)**	**3.5 (±0.2)**	**3.4 (±0.1)**	**3.4 (±0.0)**
Improve tolerance of ornamentals to varying conditions	2.2 (±0.0)	2.3 (±0.1)	2.1 (±0.2)	2.2 (±0.1)	2.0 (±0.2)	2.5 (±0.3)	2.2 (±0.3)	2.2 (±0.2)	2.0 (±0.1)	2.2 (±0.0)
Cultivation of desired special forms as ornamental trees	2.1 (±0.0)	2.2 (±0.1)	2.0 (±0.2)	1.9 (±0.1)	2.0 (±0.1)	2.6 (±0.3)	2.2 (±0.3)	2.0 (±0.3)	1.9 (±0.1)	2.1 (±0.0)
Cultivation of Christmas trees without shoot excision	2.1 (±0.0)	2.2 (±0.1)	2.2 (±0.2)	2.1 (±0.1)	2.1 (±0.2)	2.4 (±0.2)	2.3 (±0.3)	2.0 (±0.3)	2.0 (±0.1)	2.1 (±0.0)
Produce trees with special growth habit or needle colour	1.8 (±0.0)	1.9 (±0.1)	1.7 (±0.2)	1.5 (±0.1)	1.9 (±0.2)	2.0 (±0.2)	1.7 (±0.2)	1.7 (±0.4)	1.6 (±0.1)	1.8 (±0.0)
Regulate needle or leaf colour	1.6 (±0.0)	1.7 (±0.1)	1.7 (±0.2)	1.4 (±0.1)	1.5 (±0.1)	1.7 (±0.2)	1.6 (±0.2)	1.4 (±0.3)	1.5 (±0.1)	1.6 (±0.0)
Replace import of seedlings	3.2 (±0.0)	3.3 (±0.1)	3.3 (±0.1)	3.1 (±0.1)	**3.4 (±0.1)**	3.2 (±0.2)	**3.4 (±0.1)**	**3.4 (±0.2)**	3.2 (±0.1)	3.2 (±0.0)
Expand export to abroad	3.0 (±0.0)	3.0 (±0.1)	3.2 (±0.1)	2.9 (±0.1)	3.1 (±0.2)	3.2 (±0.2)	3.1 (±0.1)	3.0 (±0.3)	3.0 (±0.1)	3.0 (±0.0)

a subgroup, 35.5% (1037 respondents) stated that they lived on a property with a forest. Of the forest owners, 33.6% reported that they did not live in the same location as their forests. The third largest subgroup consisted of forest owners who had bought a forest as an investment (18.6%). The ownership of a forest through heirs collectively (8%) was the fourth largest subgroup. The three smallest subgroups were forest combines (1.9%), the ones who did not actually own forest themselves (0.5%), and the remaining proportion of respondents (2%) who did not belong to any of the aforementioned subgroups (Other, please specify).

3.1.2 Experience in the forestry sector and of vegetative propagation

Experience in the forestry sector varied considerably among and within the respondent groups. Most respondents had more than 20 years of professional experience (54%). Compared to other groups, ornamental tree producers and representatives of public forest organisations were the most experienced, since over 80% of them had over 20 years of experience.

The respondents experience regarding methods of vegetative propagation was asked as well as whether the respondent had applied regeneration material derived through vegetative propagation (all methods of vegetative propagation including SE). The majority of the respondents overall (76%) replied that they had no experience in vegetative propagation or regeneration material produced by vegetative propagation. Approximately one fifth (22%) of the respondents had some experience of vegetative propagation and only a few (1.8%; 53 respondents) replied stating that they had much experience of vegetative propagation. The majority of producers of ornamental trees (72%) declared having at least some experience regarding vegetative propagation. The least experience regarding vegetative propagation (23% of the respondents) was declared in the group ‘Private forest owner / Responsible of private forest’.

3.2 Desired traits in vegetatively propagated spruce materials

Possible advantages which could be realised by using vegetative propagation were listed (Table 2). Overall, 18 advantages affiliated with improving certain selected features increased growth, resilience, specially formed trees, and export and import of the plant material (Table 2). Respondents were asked to value each advantage on a scale from one to four: from ‘not at all important’ (value one) to ‘highly important’ (value four). Additionally, the answers “not sure” and “not related to me” were allowed.

Within all the respondent groups, the following three advantages were considered to have the most importance (mean value of answers 3.4): improve forest health and overall resilience in changing climate; improve trees’ resilience against pests, and securing the tree species from threatening biotic and abiotic risks (Table 2). The least valued possibilities among all the respondents were: Possibility to regulate needle or leaf colour; Possibility to produce trees having a special growth habit or needle colour; Cultivation of Christmas trees without the need for shoot excision and Cultivation of desired special forms as ornamental trees.

The respondents’ background had an effect on how important they considered different possible advantages, other than those valued highly among the all groups (Table 2): The producers of ornamental trees valued the high possibility of storing regenerable material for decades. The possibility to increase growth remarkably was considered important, especially among producers of Christmas trees, people responsible for public forests, seed producers, and the group “others”. Respondents responsible for public forests valued the possibility of shortening rotation time too. Together with the group “Others”, they also saw the possibility to improve wood quality as important. Of the other potential advantages, the possibility of replacing the import of seedlings was considered valuable by those respondents responsible for public forest, seed producers, and producers of ornamental trees.

3.3 Willingness to pay for improved material

Respondents' willingness to pay more for improved material varied depending on the trait (Table 3). Overall, respondents declared to be definitely willing to pay between 7 to 15% more for the improved traits, possibly even 12 to 24% more.

In the case of improved growth, the respondents' willingness to pay was additionally asked separately for varying growth improvements, and found to increase in a relatively even manner: With a 20% increase in growth, the respondents were willing to pay, on an average, 12% more; with a 30% increase in growth, 19% more; and with a 40% increase in growth, 27% more.

In the survey, the open willingness to pay (WTP) question (€ per plant) was used to estimate the attractive features of ornamental spruce trees (for their description, see Nikkanen et al. 2013) and, in total, 20 responses were given to this WTP question. Based on the WTP results, the most attractive characteristic was 'Table-top spruce' (*Picea abies* f. *tabulaeformis*) with the highest WTP, €1.60. Secondly, for the form having a regular, dense, conical crown, the WTP was €0.90/plant, and thirdly, for the globular form (*P.a.* f. *globosa*), €0.80/plant, and for the form having yellow needles (*P.a.* f. *aurea*), €0.65/plant. For other characteristics desired by the respondents, i.e., resilience, better growth rate, curliness, and strong height growth, the WTP was €0.89. These results should be taken with caution since standard deviations with such a small sample are large. The results show that the WTP for these characteristics are moderately above conventional market prices.

3.4 Risks of vegetative propagation

Among all respondents, 'depletion in genetic diversity', together with 'unknown risks related to vegetative propagation' were considered as the highest and second highest risk related to vegetative propagation from the risks defined in the survey, respectively (Table 4). The two least feared risks were 'Technology is not considered reliable on an industrial scale' and 'Prejudices towards vegetative propagation in my own industry sector', respectively. The uncertainty of the respondents regarding the achievable gain in adopting vegetative propagation was clear, as 23.3% of the respondents declared that they were unable to evaluate this, while for the other potential risks, the percentage of respondents unable to answer was only 6 to 13 (Table 4).

Table 3. Results of acceptance of price increment (%) for improved traits in trees of categories of certainty "Definitely would pay" and "Possibly would pay". Willingness to pay calculated as percentage increase (%) in both categories.

How likely would you accept a price increment for…	Definitely	Possibly
plants with known characteristics	7.3	18.7
regenerable material of the same origin for decades	6.9	22.2
tailor-made wood as raw material for industries	7.7	16.4
production of desired secondary compounds	8.1	11.7
improved growth	15	15.7
shortened rotation time	12.1	15
improved wood quality (e.g., less / smaller branches)	9.9	16.4
improved resilience in changing climate	12.5	14.1
securing species' gene pool from biotic and abiotic threats	13.6	13.8
improved fungal / decay resistance	11.9	14.5
improved resilience of ornamentals	8.9	23.6
desired special forms of ornamental trees	9.5	23
Christmas trees without need for shoot excision	15.4	21.1

Table 4. Risks related to vegetative propagation asked from the respondents in the survey in the survey of perceptions towards tree breeding and vegetative propagation, the mean values of answers on scale from one (not at all important) to four (highly important) overall presented with a standard deviation, and the proportion of respondents answering 'Cannot say'.

Risk description	Mean	Std. Dev.	Cannot say, %
Depletion in genetic diversity	3.01	0.76	5.90
Unknown risks related to vegetative propagation	2.95	0.80	12.70
Prejudices and false perceptions related to vegetative propagation	2.89	0.75	8.90
Too limited an amount of information available on vegetative propagation	2.88	0.76	9.70
Negative perception towards vegetative propagation in society	2.72	0.81	8.00
Relatively small gain when contrasted to the cost of vegetative propagation	2.70	0.79	23.30
Technology is not considered reliable on an industrial scale	2.66	0.70	13.40
Prejudices towards vegetative propagation in my industry sector	2.59	0.76	12.00

3.5 Acceptable proportion of vegetatively propagated forest regeneration material

After a short explanatory text about vegetative propagation and its effect on genetic diversity (Suppl. file S1), the respondents were asked the following question: 'In your opinion, taking genetic diversity into account, how much Finnish forest plant production could be vegetatively propagated?' Overall, 74% of respondents answered the question and 26% did not answer the question. According to the responses, on average, 36% of all forest regeneration material could be vegetatively propagated (median 32%). Responses regarding the percentage of forest regeneration material which could be produced via vegetative propagation ranged from 0 (2% of the respondents) to 100 percent (1% of the respondents).

An analysis of variance showed that those respondents having a lot of previous experience of vegetative propagation accepted 47% (the highest level of adoption), those who had some experience accepted 39%, and those who did not have any experience accepted 34%. These differences between groups were statistically significant ($p<0.01$). Similarly, their own work experience seemed to have an effect on the acceptability, and this was also statistically significant between the groups of respondents ($p=0.04$). The highest acceptability rate was in those who had over five years of experience, with a rate of 36%, while those with less than five years of experience accepted 34%, and those who did not wish to reveal their experience had the lowest acceptance rate, 28%.

3.6 Factor analysis for technological acceptance and reliability of measurement

Five theoretical constructs were identified and tailored for the questionnaire using 16 variables. A exploratory factor analysis was conducted for these five theoretical constructs (Attitude towards use [AA1–AA3], Perceived ease of use [PEU1–PEU3], Perceived usefulness [PU1–PU5], Subjective norm [SN1–SN2], Intention to adopt [IA1–IA2]) including 15 statements in total (Table 1).

The measurement of the reliability was evaluated, and all five theoretical constructs were measured separately. Cronbach's alpha gave strong support to all variables (<0.70), except PEOU (Perceived Ease of Use) which exhibited a value of 0.60. However, these variables were retained in the factor analysis since a closer analysis of reliability statistics indicated that these variables could be retained in the factor analysis (i.e., Corrected Item-Total Correlation > 0.3). In addition, the interpretation of the factor solution supported that PEOU is one of the main variables in Factor 3. The final factor solution yielded three factors (Table 5).

Table 5. Results of Factor analysis for technological acceptance and reliability of measurement; Code of Factors, Factors loadings and Communalities (see Table 1 for Code abbreviations).

Code	Factor			Communalities
	FA1	FA2	FA3	
PU3	0.749	0.335		0.673
PU1	0.725			0.583
PU5	0.716			0.553
AA3	0.681	0.434		0.653
SN3	0.673	0.353		0.578
SN2	0.646			0.495
AA1	0.632	0.479		0.632
SN1	0.618			0.406
IA2	0.597	0.425		0.543
PEOU2	0.49		–0.475	0.475
IA1-	–0.318	–0.69		0.608
PU2-	–0.302	–0.644		0.39
AA2-	–0.38	–0.636		0.596
PU4-		–0.409	0.352	0.313
PEOU1-			0.723	0.540
PEOU3-			0.56	0.343
Explanation rate (%)	41.1	7.6	4.4	
Eigenvalue	7.01	1.8	1.2	

The first factor (FA1) illustrates a highly positive attitude towards the adoption of vegetative propagation, and it was seen to be useful for the company and for the industry, and believed to be adopted soon. A perceived easiness of the adoption was also expected. The second factor (FA2) similarly had a positive attitude, but with less explanatory variables. In general, the perceived utility for the industry and for the company was expected. FA2 differs from the FA1 only in the statement about perceived utility, and adoption was not considered too costly for the industry.

The third factor (FA3) had more critical opinions about the adoption of vegetative propagation. The perceived ease of use was the main dominant in FA3, but this factor also illustrates opinions that adoption was considered too expensive for the industry.

Next, the calculated means of the factor scores against the respondent's experience of the industry and of vegetative propagation were explored. FA1 and FA2 had a statistically significant ($p < 0.01$) difference when the means of the factor scores were compared against the respondents' experience of the industry. The highest mean in FA1 was in respondents that had five to ten years in the industry, and the highest for FA2 was for those who had been in the industry for over 11 years. The highest mean in FA1 was also for those who responded with having 'some' or 'much' experience in 'vegetative propagation'.

4 Discussion and conclusions

4.1 Respondents to the survey

The survey yielded altogether 2925 answers, and the majority (almost 90%) of the respondents were forest owners. However, only 4.4% of the forest owners to whom the questionnaire was sent replied.

Even though the number of respondents belonging to the groups 'Seed producers' and 'Forest plant producers' is small compared to the group 'Private forest owners', these groups can be considered well represented, since there are only a few forest seed producers in Finland, and also a limited number of forest plant producers (Official statistics of Finland 2019). On the same basis, Christmas trees can be considered well represented in this study, as the survey was disseminated through the Christmas tree society to its members. It is difficult to estimate how well the producers of ornamental trees were covered as there was no statistics of how many producers there were overall. Additionally, many of the producers of ornamental trees are known to produce ornamental trees as a side product of, i.e., forest plants. Those working for public and private forest organisations were not especially reached in this study but more likely encountered as a side product, probably due to the multiple roles of the respondents. These groups were, however, included in the study to record the views of people having an influence within the forest organisations.

Most of the Producers of ornamental trees declared having experience of vegetative propagation, which can be explained by the fact that specially formed trees are often vegetatively propagated (Nikkanen et al. 2011, 2013).

4.2 Desired traits in vegetative propagated material

In the survey, the listed possible advantages or characteristics of vegetatively propagated material were chosen based on recent results on achieved, or otherwise considered realistic. The potential gain in growth by the utilisation of vegetatively propagated forest regeneration material (20 to 40%) was estimated based on projections of realised genetic gain achieved with genetically improved seedlings (Jansson et al. 2017; Haapanen 2020; Ahtikoski et al. 2020), and by taking into account both theoretical studies and experimental data from progeny and clonal trials indicating that extra genetic gain (5 to 25%) is possible in conifers from clone testing and deployment (Wu 2019). Additionally, resilience against pests, e.g., European pine weevil (*Hylobius abietis* [L.] [Col., Curculionidae]) and pathogens, e.g., root rot (*Heterobasidion parviporum* Niemelä & Korhonen), were included in this survey. Recent Swedish studies indicate that Norway spruce SE plants are more resistant against pine weevil than seedlings of the same genetic background, potentially due to the priming of defence genes during propagation (Puentes et al. 2018). Additionally, a gene affecting resistance against root rot has been discovered, which improves the possibility to incorporate genomic selection in tree breeding (Nemesio-Gorriz et al. 2016). Overall resilience to withstanding varying climatic conditions can be improved by selecting phenotypes with late spring phenology into breeding and propagation materials (Napola 2010).

In the case of trees intended for ornamentals, landscaping or for Christmas trees, the interest towards potentially valuable phenotypic features was asked in the questions, including, e.g., peculiar needle colour (red or yellow) and growth habit (narrow-crowned, dense conical, globular), which are known to be inheritable and are possible to be obtained through crossing (Nikkanen et al. 2011).

Regardless of the respondent group possibilities, improving the resilience of forest in changing climates, against pests, and securing species' gene pool were regarded as highly important. In addition, in the recent European survey on stakeholder demands and perceptions on improved forest generation material performed by the European Forest Institute (EFI), the respondents representing public administrators as well as public and private forest managers from nine European countries considered the improved resilience of Norway spruce forest regeneration material very important, with drought resistance being the most valued trait (European Forest Institute 2019). The current results indicate that the respondents are aware that new biotic and abiotic threats will probably arise in the future. These new threats may affect those perceptions favouring resilience as the rotations are long, rather than thriving for maximising growth only. Improving overall resilience is the focus of forest tree breeding in Finland as one of three main breeding targets (Haapanen and Mikola 2008), and it will have a large financial effect on silviculture in the coming decades (Jansson et al. 2017).

Slightly surprisingly, the producers of Christmas trees and ornamental tree producers, did not differ from other respondent groups regarding the possibilities, even though several possibilities introduced in the survey could be presumed attractive to them. Perhaps they already mastered the production, and feared competition or lower consumer prices with improved methods, or were more conservative or realistic towards the possible gains in their field. Another option is that these groups thought of the possibilities in a wider context than only within their own field, which expresses concern towards forest health.

4.3 Willingness to pay for improved material

The results indicate that respondents, who were mainly forest owners, understand the gains possibly achieved by using improved forest regeneration material, not only vegetatively propagated. Respondents reported a modest willingness to pay for improved traits. This current result is in line with a recent European survey, in which the respondents considered that in Norway spruce investment in improved forest regeneration material is fully compensated and provides some gain (European Forest Institute 2019).

When examining the responses for the desired traits and willingness to pay for improved characteristics, an interesting contradiction is seen, i.e., improved growth was highly valued only among some respondent groups, but there was definite willingness to pay extra for it. Likewise, the possibility of growing Christmas trees without the need for shoot excision was not considered important – not even among Christmas tree producers – but the definite willingness to pay more for this kind of material was the greatest.

According to Lelu-Walter et al. (2013), the cost of vegetatively propagated material is a big problem which results in an unwillingness to use this material in forest regeneration. Even though additional costs can be recovered through the increased wood volume, quality, and uniformity of the material, the problem is one of cash flow. The additional cost today will not be fully recovered until the forest crop is harvested. This is probably reflected also in the responses of the present study: Even if there is willingness to pay more, the acceptable price increment is relatively small, up to 24%, depending on the trait. The price of SE material has been previously evaluated to be at least twice that of seedlings due to high labour costs at certain steps of propagation requiring manual handling of individual embryos, and lower conversion rate compared to improved seeds (Lelu-Walter et al. 2013), and the same cost structure is seen in Norway spruce SE (Tikkinen 2018). The acceptable price increment can thus be achieved only through automation of the labour-intensive part of the process, as already partly realised in Canada for white spruce and Norway spruce (Bonga et al. 2019), and being developed elsewhere (Egertsdotter et al. 2019) too.

It should also be noted that the financial gains of using improved material, and, consequently, potentially also the willingness to pay for this, may change in a relatively short period of time if forest owners in future would, for example, receive financial compensation for carbon fixation. In a recent study, Ahtikoski et al. (2020) showed that including carbon pricing (i.e., timber production combined with carbon sequestration) with genetically improved material improves financial performance compared to pure timber production. Furthermore, the proportion of carbon benefit (%) of absolute bare land value fluctuates between 27% and 42%, indicating a substantial role of carbon sequestration in financial performance.

4.4 Risks and benefits of vegetative propagation

Risk analyses of using clonal material in forestry have recently been performed in Sweden: Wu (2019) recognises three risks, i.e., the risk of plantation failure, the risk of diversity loss at the forest and landscape levels, and the risk associated with the success rate of vegetative (or SE) propagation. Among the Finnish respondents in the present study, the risk related to the depletion of genetic diversity was considered the most severe, while the risk related to technology not being reliable on an industrial scale was considered smaller.

There are several theoretical models to assess risk and to determine the number of clones required to mitigate the risk of losing genetic diversity, as reviewed by Wu (2019). Several studies support that a 'safe' number of clones (unrelated) is between 5 and 30, and that the optimum level of diversity might be around 18 clones, with a minimum of around 6 (Burdon et al. 2003; Rosvall 2019a; Rosvall et al. 2019a). Compared with these recommendations, the current pilot propagations in Finland performed with 120 genotypes from 12 non-related families (Tikkinen et al. 2019) can be evaluated to mitigate the risk for loss of genetic diversity very well, and enables further selection based on traits of individual genotypes. In such a pilot propagation lot, a large cell-line propagation margin exists, allowing variation in the propagation success of cell lines, which was introduced as an operational guideline by Rosvall et al. (2019b).

In Europe, the marketing of forest reproductive material is regulated by Council Directive 1999/105/EC. This directive is implemented in Finland by the Act on Trade in Forest Reproductive Material (241/2002) and the Decree on Trade in Forest Reproductive Material (1055/2002). Finnish legislation regulates in which type of basic material and category of forest reproductive material vegetatively propagated material may be marketed. Depending on the type and category of basic material, Finnish legislation regulates the maximum amount of plants brought to market on a family or genotype level in category "qualified", and limits the minimum number of clones included in clonal mixtures as reviewed by Tikkinen and coworkers (2019). The national regulations within the EU differ, as, e.g., in Sweden, the regulations based on using vegetatively propagated material are tied to a maximum areal limit or percentage of landholding as reviewed by Rosvall and coworkers (2019a).

Bradshaw et al. (2019) elaborated on the ecological risks associated with SE of Norway spruce in light of the current natural population structure of the species. They recognised a loss of genetic diversity, a loss of adaptation of tree populations, and changes in other components of the ecosystem due to genetic changes of the dominant forest tree as the most likely sources of threats. Bradshaw et al. (2019) suggest that the naturally high phenotypic plasticity and relatively low genetic diversity in *Picea* reduces the importance of short-term clonal variation within central regions of the climatic range of the species. Greater genetic diversity and an increased clone number is however required at range limits where strong selective pressures are likely in the near future. In order to retain ecological benefits associated with natural forest areas, it is also recommended to confine clonal forestry techniques to existing intensively managed forest or former agricultural land. Other risk management strategies include diversifying silviculture to improve both the biological and recreational values of clonal plantations, as well as changing clonal mixtures through time as part of a managed breeding programme (Bradshaw et al. 2019).

The benefits of using improved forest regeneration material and vegetative propagation are beyond those included in this survey. In this survey, the possible benefits thought to be relevant to different groups of respondents were included with some constraints listed above. In a wider sense, the benefits include, e.g., the following scenario described by Rosvall and coworkers (2019a): Through the utilisation of vegetative propagation, forest growth may be significantly increased, which may result in focusing forest production on a smaller area, and therefore reducing the competition among different types of forest and land use.

Through the benefits highly valued by respondents, improving resilience and resistance against pests and pathogens, forest health may be sustained in the future. Additional benefits through these possibilities include the reduction of emissions and greenhouse gasses by the reduced use of fertilizers, pesticides, and fungicides, as concluded by Lundmark et al. (2014). Additionally, respondents highly valued the possibility to secure a species gene pool from biotic and abiotic threats. One example of conserving a threatened species via vegetative propagation can be found in the American chestnut (*Castanea dentata* [Marshall] Borkh.) (Nelson et al. 2014). Significant improvements with conifers in wood quality growth and resistance against pests and diseases have been demonstrated possible and also achieved with several species as reviewed by Wu (2019). Through implementing the breeding results straight to forest regeneration and the intensive selection of traits and characteristics of the propagated population, vegetative propagation can be efficiently applied to adapt forests to the changing climate as concluded by Rosvall and coworkers (2019b).

Vegetative propagation through SE is applied for different coniferous species around the world. As recently reviewed by Wu (2019), radiata pine (*Pinus radiata* D. Don) is clonally propagated in New Zealand (2.5 to 5 million trees annually, up to 11 % of all reforestation materials) and Australia (approximately 20 million per year), the sold material being rooted shoot cuttings. In New Zealand, however, SE is used to produce organogenic cultures from which the shoots for rooting are taken (Moncalean et al. 2016). In the southeastern USA, around 2 % of loblolly pine (*Pinus taeda* L.) is sold as tested clonal varieties (Wu 2019). In Canada, JD Irving Limited produces forest regeneration material of white spruce (*Picea glauca* [Moench] Voss) and Norway spruce by SE, with increasing annual production numbers, the current annual SE propagation being 2.5 million (Andrew McCartney, pers.comm.). In Europe, vegetative propagation is used for Sitka spruce (*Picea sitchensis* [Bong.] Carrière) that is propagated as rooted cuttings in Scotland (8 million per year, 25% of Sitka spruce material) and in Ireland (3 million per year), the donor plants for cutting production in Ireland having been produced by SE (Thompson 2013; Wu 2019). In Sweden, SweTree Technologies is currently building a facility for Norway spruce SE propagation, aiming to annual production of 2 to 20 million plants (Magnus Hertzberg, pers.comm.) According to Wu (2019), genetic gains in growth and quality in the reported cases are clear, and also economic gains of using clonal material demonstrated e.g. in radiata and loblolly pine. Information on evolution of SE programmes is, however, often difficult to obtain due to intellectual property issues or business secrets.

4.5 Acceptability of vegetatively propagated materials

Public acceptance towards vegetative propagation applied in forestry has been identified as a critical challenge in Europe, which needs to be adequately addressed (Lelu-Walter et al. 2013; Rosvall et al. 2019b). The current survey indicates that both positive and negative attitudes remain towards the adoption of vegetative propagation. Positive attitudes were linked to usefulness, easiness of use of the new technology and perceived utility for the forest owner or for the industry. It has also positive effect if relevant actors of the industry will adopt it. Negative attitudes arose if new technology was considered as difficult to use and too costly. Most of the respondents, which were mainly forest owners, accept a portion of forest regeneration material produced via vegetative propagation. From the respondents, 74% answered this question, and although the responses varied considerably, according to the respondents, roughly one third (response mean 36%, median 32%) of the annual reforestation material in Finland would be acceptable to be produced via vegetative propagation. However, it must be taken into account that the result does not represent the “general public”, rather only forest owners and some affiliated groups.

Most of the positive respondents towards the technological adoption had been involved in forestry for more than 5 years. The most positive attitude was found in those with over 11 years of experience in forestry who did not consider adoption too costly for the industry. Those who already had at least some degree of previous experience about vegetative propagation also had a positive attitude towards adoption.

The results are encouraging, indicating that forest owners and some related sectors do not completely reject vegetative propagation, although some risks are involved. This lays a good foundation to ensure support in society and the political world to apply vegetative propagation through communication of the benefits and how the risks are managed (Mátyás 2000; Rosvall et al. 2019b).

4.6 Constraints

When providing background information for the respondents to the survey, there is a risk of directing the attitudes of the respondents towards certain answers. This study attempted to plan the background information to the survey so that the respondents to the topic would be informed in a neutral manner, however the effect cannot be completely excluded. The targeting of the survey may also be criticised as the survey was disseminated via registered associations to their members, and only to forest owners whose estates areas were average-sized or larger. Targeting these forest owners may be justified, as there are hundreds of thousands of forest owners in Finland, and to save resources, the number of targeted respondents had to be limited somehow. The forest owners with average or large estates may be expected to be more accustomed to forest regeneration and silvicultural operations, but in such a large number of respondents, covering the whole of Finland, the group can be considered a representative sample of forest owners.

Since hypothetical valuation methods do not deal with real money, they are not incentive-compatible. Different instruments have been developed to mitigate any hypothetical bias (Carson 2000). A payment vehicle format was applied that allowed the expression of uncertainty during the valuation task and this is one method to mitigate any hypothetical bias. Vossler et al. (2003) presented findings that the proportion of willingness to pay question to ‘‘Definitely would pay’’ and ‘‘Probably would pay’’ responses are good predictors of actual contributions for a good. Accordingly, in this study we explored hypothetical, but familiar private good, i.e., a plant that included improved traits of desired properties of vegetative propagation, meaning that the product itself was familiar to the respondents.

Regarding the questions asked, a question related to “willingness to pay for improved pest resistance in forest regeneration material” was unfortunately not asked. What makes this even more unfortunate, is that this was one of the most valued traits among respondents.

4.7 Conclusions and prospects

The present study indicates that, the respondent’s perceptions do not hinder the application of vegetative propagation in forest regeneration, although more communication is needed to increase awareness. In this survey, interest was indicated towards the possible gain from vegetative propagation, along with some concerns and risks. The respondents valued some traits which could be implemented through tree breeding, e.g., genetic improvement, and reported some willingness to pay for these improved traits. However, the survey does not concern the general public, but mainly forest owners and few selected sectors (some of which were by-products from forest owners due to multiple roles), and the attitudes and perceptions of the general public need to be investigated and addressed. The current novel study provides valuable background for communicating the benefits and risks of vegetative propagation in forest regeneration to a wider audience.

Authors' contributions

Mikko Tikkinen had the main responsibility in writing the manuscript and dissemination of the survey to respondents, participated in developing the questions and survey forms.
Terhi Latvala had the main responsibility in technical realization of the survey forms and carrying out the statistical analysis and participated in writing the manuscript.
Tuija Aronen had the main responsibility in planning the question asked in the survey and participated in writing the manuscript.

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Supplementary files

S1.pdf; English translation of a short explanatory text (original text in Finnish) about vegetative propagation and its effect on genetic diversity provided for respondents in the beginning of the survey, available at https://doi.org/10.14214/sf.10506.

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