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Early measures for forest stand establishment within the context of climate change in Europe

Frühe Maßnahmen zur forstlichen Bestandesbegründung im Kontext des Klimawandels in Europa

Benno Eberhard[1,2*], Sara Bergante[3], Karol Bronisz[4], Tiina Laine[5], Christophe Orazio[6], Raffaele Spinelli[2], Marcela van Loo[1]

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Abstract

Under exacerbated environmental conditions due to climate change and more frequent and more severe disturbances the establishment of forest stands has become a challenge for forest managers. This study aims at comparing stand establishment methods on a European scale. We differentiated between five biogeographic regions to detect similarities and differences regarding current practices as well as trends considering the climatic background using an expert survey. Our results allowed identifying two clusters, one boreal cluster and one European mainland cluster. In both cases mechanical soil preparation and measures against drought are seen as

[1] Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW), Institute of Forest Growth, Silviculture and Genetics, Seckendorff-Gudent-Weg 8, 1131 Vienna, Austria
[2] Consiglio Nazionale delle Ricerche-Istituto per la Bioeconomia (CNR IBE), Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy
[3] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria – Centro di ricerca Foreste e Legno (CREA-FL). St. Frassineto Po 35, 15033 Casale Monferrato, Italy
[4] Warsaw University of Life Sciences, Department of Forest Management, Dendrometry and Forest Economics, Nowoursynowska Str. 159 building 34, room 1/84, 02-776 Warsaw, Poland
[5] Metsa Group, Asemakatu 7 3. Krs, 70110 Kuopio, Finland
[6] Institut Européen de la Forêt Cultivée (IEFC), 69 route d'arcachon, 33610 CESTAS, France
*Corresponding author: Benno Eberhard, benno.eberhard@gmx.at

key factors. Experts from the boreal region give high importance to appropriate plant material and fertilization for growth acceleration, and consider insects and fungi as a primary threat. In the mainland cluster, experts rely mainly on silvicultural measures and expect damage by game to be highly detrimental for stand establishment. Across Europe the preferable countermeasure to face drought is not irrigation but a combination of strategies related to mechanical site preparation, plant material, planting method, and silviculture. This study identifies three focal areas for forest practitioners to consider when establishing new forest stands:

(1) careful selection of the plant material;
(2) suitable site preparation and
(3) prudent deliberation on beneficial silvicultural options.

Zusammenfassung

Aufgrund der negativen Folgen des Klimawandels ist die forstliche Bestandesbegründung zu einer Herausforderung für Waldmanager geworden. Ziel der vorliegenden Arbeit ist es, Bestandesbegründungsmaßnahmen auf europäischer Ebene zu untersuchen. Nach Ausscheidung fünf biogeografischer Regionen wurde mithilfe einer Expertenbefragung ermittelt, welche Gemeinsamkeiten und Unterschiede bzw. welche Trends es hinsichtlich aktueller Praktiken zur Bestandesbegründung gibt. Die Ergebnisse zeigen, dass zwei Cluster unterscheidbar sind, ein borealer Cluster und ein europäischer Festlandcluster. In beiden Fällen gelten mechanische Bodenbearbeitung und Maßnahmen gegen Trockenheit als Schlüsselfaktoren bei der Bestandesbegründung. ExpertInnen der borealen Region legen großen Wert auf geeignetes Pflanzenmaterial und Düngung zur Wachstumsbeschleunigung und sehen Insekten und Pilze als zentrale Risikofaktoren. ExpertInnen des Festlandclusters setzen hauptsächlich auf waldbauliche Maßnahmen und betrachten den Wildeinfluss als Hauptschadensfaktor. Für alle Regionen besteht die erfolgversprechendste Maßnahme gegen Trockenheit nicht in Bewässerung, sondern in einer Reihe nachhaltiger Strategien zur Verbesserung der Wasserversorgung durch mechanische Bodenvorbereitung, geeignetes Pflanzenmaterial, geeignete Pflanzmethoden und Waldbau. Unsere Studie erlaubt folgende Empfehlungen für die forstliche Praxis der Bestandesbegründung:

(1) Wahl von geeignetem Pflanzmaterial,
(2) Maßnahmen der Bodenvorbereitung und
(3) wissensbasierte Anwendung waldbaulicher Maßnahmen.

1 Introduction

Early measures to ascertain the successful establishment of forest crops play a key role during the forest management cycle (Mc Carthy *et al.*, 2017; Orazio *et al.*, 2019). To achieve successful establishment on a particular site, the young plants need to

develop a robust root system for stability as well as for sufficient water and nutrient uptake. During the juvenile stage, trees are highly sensitive to unfavourable site characteristics, to weed competition, and to eventually occurring human treatment deficiencies (Lyr, 1996; Ritchie & Dunlap, 1980). This holds true and is even exacerbated in the context of climate change (Norby & Jackson, 2000).

In Europe, 94% of the forests are semi-natural, 3.9% are plantations and 2.2% are classified as undisturbed. The forests provide the habitat for 454 native tree species (Rivers *et al.*, 2019) out of which 100 to 120 are of relevance for forestry (Alia *et al.*, 2021). In total, the share of conifers and broadleaves is 46% and 37%, respectively, the rest represents mixed forest stands. The average percentage of areas under special rules of conservation with mostly no wood harvest is 24%. The contribution of the single European regions to this figure reveals large differences, e.g. in Central-West Europe 92% of the forests are available for wood supply while in South-East Europe 53% are managed with a prevailing commercial purpose. Out of European forests, 66% are naturally rejuvenated (Forest Europe, 2020a), the rest is artificially reforested.

The choice of early measures for the forest stand establishment depends on the geographic region where the measures are applied (Ammer *et al.*, 2011; Ramantswana *et al.*, 2021). Even though tree species distribution and tree species diversity are driven by nature, the human intervention has an enormous impact on the forest coverage. In particular, the relevance and priority of establishment measures may differ from country to country and between regions from the North to the South and from the West to the East. In the Nordic region, site preparation after final felling is needed for a better seedling survival rate and increased growth (Sikström *et al.*, 2020). Even if mounding has replaced disc trenching as the most common site preparation method for planted seedlings, disc trenching is still in use when sowing seeds (Official Statistics of Finland, 2022). Mounding is also considered an efficient measure against the pine weevil (*Hylobius abietis L.*) damages (Löf, 2000). For Norway spruce (*Picea abies L. Karst.*) in Finland Luoranen & Viiri (2021) demonstrated a higher survival rate of the young plants in mechanically prepared spots in comparison to young plants in untreated patches. Polish studies revealed that mechanical site preparation is recommended not only to create optimum conditions for the pine growth in naturally regenerated sites after clear cut, but also when planting and seeding (Aleksandrowicz-Trzcińska *et al.*, 2017). For the successful establishment of sessile oak (*Quercus petraea Matt.*) and maritime pine (*Pinus pinaster Ait.*) in central France, mechanical site preparation has been identified as a key factor since it enables to control aggressive weeds such as moor grass (*Molinia sp.*) and eagle fern (*Pteridium aquilinum L. Kuhn*) (Auzuret *et al.*, 2014). In Italy, the management of poplar plantations that are expected to assume relevance in the future due to the steadily increasing demand for quality fiber and renewable energy sources (Anderson *et al.*, 2015), face intensive treatment. The key elements in this respect are insect control, fertilization, pruning, and irrigation which always more becomes an essential premise for the plant survival (Marchi *et al.*, 2022). Conversely, chemical weed control and fertilization activities are loosing importan-

ce, in full agreement with the FSC and PEFC regulations (Nermin & Francesco, 2021). For poplar plantations in Sweden (Böhlenius & Övergaard, 2015) demonstrated that the choice of plant material and mechanical site preparation are crucial for the stand establishment. Poplar plantations play a significant role also in the French forestry sector, where they are intensively managed, but not irrigated.

The success of one and the same measure may vary with the region of application (Löf *et al.*, 2012). In an experiment with conifer species the primary advantage of soil scarification was weed control (Munson *et al.*, 1993). In contrast, in boreal forests the most beneficial effect of the same measure was seen in the ability to break up the thick humus layer and to trigger the mineralization process, which leads to enhanced nutrient uptake (Schmidt *et al.*, 1996). And again, the same measure can bring yet a different benefit in semi-arid zones, where harrowing is applied mainly to decrease water evaporation and to increase infiltration (Querejeta *et al.*, 2001).

Available literature (Cortina *et al.*, 2004; Coyle & Coleman, 2005; Fiala *et al.*, 2010; Stanton *et al.*, 2002; Stanturf *et al.*, 2001; Steele *et al.*, 2021) suggest that three main groups of stand establishment measures can be classified:

(1) use of appropriate plant material,
(2) resistance to biotic damages,
(3) enhancement of site conditions and increase of resource availability.

The latter group includes three elements, mechanical site preparation, water supply, and nutrient supply (Cortina *et al.*, 2011). The provision of resources undeniably is a key requirement for plant growth. Apart from the fact that water as well as nutrients can be added from outside to a stand (irrigation, fertilization), there is a second strategy that aims to achieve the same goal by making efficient use of the resources that are already present in a stand. This is called the sustainable way of water and nutrient supply, within the framework of this study. All before-listed measures, if adopted properly, are competent to contribute to this effect: Mechanical site preparation, by loosening up compacted soils, increases infiltration rates, improves hydraulic conductivity, reduces water runoff, prevents water stagnation, slows down capillary evaporation, facilitates root penetration, and removes weed competition (Cortina *et al.*, 2011; Löf *et al.*, 2012; Lowery & Gjerstad, 1991). The plant material, by means of the stomatal behaviour and the root shape of the used exemplars, has impact on the uptake of water and nutrients (del Campo *et al.*, 2020). Right planting techniques might optimize the root geometry and this way also contribute to the successful uptake of resources (Lobet *et al.*, 2014; Steudle, 2001). And silvicultural measures, when directed to create favorable environmental conditions, maximize the use of available resources. This is comparable to techniques in agroforestry targeted to create positive interactions between plant layers, this way reducing transpiration (Padilla & Pugnaire, 2006).

This study aims to collect information about the main stand establishment techniques (measures) currently practised in Europe, and to detect trends in future refores-

tation strategies. It is of interest to view the captured measures against the climatic background within greater European regions such as north Europe, central west Europe, central east Europe, and the southern part of the continent. In analogy with the Köppen-Geiger climate map (Geiger, 1961) in the updated form according to Peel *et al.*, (2007), these regions in rough outlines exhibit the following climatic conditions: *North Europe* has a boreal climate with a rather evenly distributed precipitation. More northerly in this region, the characteristic is subarctic with cold winters and cool summers, while the southern part is humid continental with reasonably cold winters and mild summers. The temperature is specific to the climate zone *D* (*cold*) which means that the warmest month is beyond 10°C, and the coldest month is equal to or below 0°C. In *central west Europe*, the prevailing climate type is temperate oceanic with warm summers, no dry season, and a rather equally distributed rainfall. The temperature as being characteristic of the climate zone *C* (*temperate*) includes a warmest month beyond 10°C, and a coldest month ranging between 0°C and 18°C. In *central east Europe*, the dominating climate type is temperate continental which indicates reasonably warm summers, cold winters, no dry season, and also a principally evenly distributed rainfall. Also here, the temperature is typical for the climate zone *D* as described before. In *south Europe* where the temperature likewise represents the *C*-zone, three main climate types are predominating: The warm mediterranean climate includes drought periods with a precipitation of the driest month in summer being below 40 mm. The warm oceanic climate integrates hot summers with a mean temperature of the warmest month greater than 22°C, but no dry summers, according to the updated Köppen-Geiger climate map. The temperate oceanic climate, likewise present in south Europe, was already characterized above.

The following research questions are posed for the study:

1. What are the key aspects at the establishment phase?
2. What are the most severe problems/obstacles encountered during stand establishment?
3. Have the priorities of early measures changed during the last ten years in the context of global warming, and how are they expected to change within the upcoming ten years?
4. Are there patterns in the differences and/or similarities between climatic regions, and if so, how can these be interpreted?

2 Methods

The data acquisition for the study was done by a questionnaire survey. This technique was preferred to a literature review because it enables to strive for information about most recent developments in stand establishment practices, which may have not been documented through publication yet. Experts and practitioners tend to publish their methods with a time-lag and rather in national journals (grey literature) – not as

international scientific papers. The survey technique provides a high level of uniformity and comparability of the gathered information (Brancato *et al.*, 2006).

The arrangement of Europe in large-scale biomes was oriented towards the concept of the European biogeographical regions as defined by the European Environment Agency (Cervellini *et al.*, 2020; Walday & Kroglund, 2002). Five regions were differentiated: Boreal, Atlantic, Continental, Atlantic-Continental, and Atlantic-Mediterranean. For each of these regions, practitioners and experts in the field were selected.

2.1 Survey design

The workflow for the survey followed the principal guidelines indicated in the specialized literature (Bird, 2009; Brancato *et al.*, 2006; Sarantakos, 2017). After defining the objective of the study, the conceptualization, operationalization, and pilot testing of the survey were achieved through expert group meetings attended by researchers and forest managers with expertise in this field. In agreement with the above-mentioned classification of stand establishment measures, the focus of the questionnaire was on three principal topics:

i) mechanical site preparation for reducing soil compaction,
ii) water supply, including irrigation and sustainable alternatives and
iii) nutrient supply, including fertilization and sustainable alternatives.

Irrigation was defined as water being carried from an external water source to a forest stand, while sustainable alternatives were defined as all measures to improve the benefit from the water already available in the stand.

2.2 Survey structure and implementation

Research questions one and two were intended to assess the key aspects for a successful stand establishment on the one hand (question one), and the principal risks on the other hand (question two). Both were open questions, and extent as well as level of detail of the given answers, was left to the choice of the respondents. Research question three aimed to determine the urgency of measures against drought, measures of fertilization against nutrient deficiency, measures of fertilization to accelerate growth, and measures against soil compaction, for the past (10 years back), the present, and the future (10 years from now). It represented closed and quantitative questions, and an ordinal scale ranging from one (very low) to five (very high) was adopted.

The questionnaire featured a two-part structure, whereby general information was collected in the first part and a description of concrete measures in the second part

(supplementary material). The information needed to answer the research questions, was mostly sourced from part one. Part two was designed to contribute to a better understanding of the statements provided in the first part, especially for the aggregation of the answers into categories with the intention to reduce their complexity. The survey was issued in four languages: English, German, Italian, and Polish (see supplementary material). It was delivered as an e-mail attachment and the respondents filled out the form independently so that any bias caused by the presence of the interviewer was excluded.

2.3 Selection of the survey respondents

The respondents were searched within the before-listed five biogeographic regions. Five main countries were selected to represent the regions, Finland, Poland, France, Austria, and Italy. Additional five countries were added later: Norway, Slovakia, Hungary, Bulgaria, and Spain (see Table 1). The data collection was supported by the personal networks of the authors within these countries. This was advantageous since the success of a survey research to high degree depends on the willingness of the respondents to take their time and to properly fill out the questionnaires.

Table 1: European sub-areas, biogeographic regions, and countries (two-digit ISO country code) addressed by the survey. For the division criteria of the regions, see explanations in the text.

Tabelle 1: Teilgebiete, biogeographische Regionen und Länder Europas (Länderbezeichnungen gemäß ISO-Code), die für den Fragebogen ausgewählt wurden. Zu den Auswahlkriterien siehe den Text.

European sub-region	Biogeographic Region	Representative countries
North Europe / Fennoscandian region	*Boreal*	Finland (FI), Norway (NO)
East Europe	*Continental*	Poland (PL), Slovakia (SK), Hungary (HU), Bulgaria (BG)
West Europe	*Atlantic*	France (FR)
Central Europe	*Atlantic-Continental-*	Austria (AT)
South Europe	*Atlantic-Mediterranean*	Italy (IT), Spain (ES)

We targeted 65 senior experts (respondents) with a strong professional background in operational practice, public administration, or the academia. All respondents had expertise in the standard management systems (high forest, short-rotation plantation, and nursery) as adopted by FAO (2020).

2.4 Evaluation of the survey

Research questions one and two as being open questions elicited a large variety of answers by the respondents. Therefore, the provided answers were grouped to obtain a concise overview on the practices in place, and to make the outcome manageable for further analyses. For that purpose, two aspects out of all listed aspects per question were taken in consideration, respectively. The reason was that all filled questionnaires contained at least two entries for each of the two questions, but some contained not more than two entries. The process of aggregation comprised two steps, leading to several sub-categories which have been further condensed to main categories. An example might illustrate this: One filled questionnaire for question one (*What are the key aspects?*) provided the following answers:

1. choice of the appropriate tree species,
2. mulching the area,
3. slash removal previous to mulching in order to keep the mulch-layer thin.

In this case, the first two aspects were taken in consideration. Answer one was attributed to the sub-category *choice of the right tree species/clone*, and to the main category *silviculture*, and answer two was matched with the sub-category *soil preparation*, and with the main category *mechanical site preparation* (which besides the *soil preparation* contained *mechanized weed control* as second sub-category). In case of uncertainty about the meaning of given statements, a clarification was achieved through personal contacts between the lead author and the survey respondents, and through the lead author's visits to sites in Finland, Poland, Austria and Italy between July and October 2021.

On the assumption that early measures might have a positive effect on sustainable water/nutrient supply as explained above, in the context of question one (*What are the key aspects?*) it was possible to determine whether the practices described by the respondents were comprehended as sustainable methods of water or/and nutrient supply or not. This was done based on explicit reference associated with the answers to questions one and/or two, and/or by referring to the context (part two of the survey with description of concrete measures), and personal communications with the respondents. Again, an example might be helpful for the understanding: A respondent listed as a key aspect *deep site preparation*. As can be seen, there is no explicit statement available indicating that this measure might serve as sustainable method for the water supply. Even so, as principal problem (question two *What are the most severe problems?*) the respondent mentioned the *water scarcity*. Moreover, in the second part of the questionnaire (description of concrete measures) the same respondent described *deep ploughing* as a measure out of the complex mechanical site preparation, and explicitly stated that it should be done *at the end of the vegetative season prior to planting so that the soil has the chance to absorb and store the water during the winter*. Hence, in this case the listed key aspect *deep site preparation* was interpreted to serve as sustainable measure for the water supply, in the intention of the respondent.

2.5 Statistical analysis

For the evaluation of research questions one and two, the entries were counted (frequencies) per region and category and expressed as percentages of the total number of entries for a respective region and category. A statistical assessment of the region-specific differences was done by a Pearson's Chi square-Test. To that end, the percentages (question one) were converted into corresponding numeric values. For question three, not available values (NAs) were replaced by the respective median of available values, according to region, measure (against soil compaction, against drought, against nutrient deficiency), and time dimension (present, future, past) (Table 2). On that basis, the mean values were calculated for illustration purposes in the following text. Changes in the urgency of specific measures were gauged through the difference in their intensity rating between future and past, separately for each region. A statistical verification was done by a Kruskal Wallis-test (W. H. Kruskal & Wallis, 1952), followed by the Dunn-test as a post-hoc assessment of differences between the single pairings. For the evaluation of research question four, two techniques were applied, the PAM (Partitioning Around Medoids) technique (Kaufman & Rousseeuw, 2009), and the non-metric multidimensional scaling (nmds) algorithm (Borg & Groenen, 2005; Galbraith *et al.*, 2002). PAM is a clustering method of the medoid type (Rai & Singh, 2010), which represents observations as cluster centres (medoids) that best represent a particular cluster. As consequence, the medoid can be used to characterize a cluster in its essential traits. The PAM method has two major advantages: first, that categorical variables can be integrated and, second, that it is less sensitive to outliers. For mixed data types, consisting of numerical and categorical data (see Table 2), the Gower distance was applied to quantify the distance between individual points (Ranalli & Rocci, 2019). The number of clusters adopted for the analysis was selected after determining the Silhouette width. The estimate for the goodness of clustering was the Silhouette coefficient (Rousseew, 1987). For the nmds-plots, the Bray-Curtis dissimilarity measure was chosen. The estimation of the goodness of fit of the nmds model occured by the Kruskal stress type one which was interpreted along the rating scale (J. B. Kruskal & Wish, 1978): 0.2 and below (poor fit), 0.05 and below (good fit), 0.00 (perfect fit). The level of significance for all statistical analyses of this study was $\alpha=0.05$. All analyses were performed with the statistical software R (R Core Team, 2022).

Table 2: Overview of the info and data from the 43 filled surveys with the corresponding biogeographic region and country. Atl for Atlantic, Med for Mediterranean, Cont for Continental, Ess asp for Essential aspect, Mech SP for Mechanical site preparation, Pla meth for Planting method, Silv meas for Silvicultural measures, Plant mat for Plant material, Pr pro for Principal problem, Ins Fu for Insects/Fungi, Game d for Game damages, Silv ins for Silvicultural insufficiency, D for Against drought, F for Fertilization, N for Against nutrient deficiency, A for Promoting growth, SC for Against soil compaction, p for past, P for present, F for future, 1 stands for very low, 5 for very high.

Tabelle 2: Zusammenfassung der Daten aus den 43 ausgefüllten Fragebögen, gemäß biogeografischen Region und Ländern. Atl steht für Atlantisch, Med für Mediterran, Cont für Kontinental, Ess asp für Entscheidender Punkt, Mech SP für Mechanische Bodenvorbereitung, Pla meth für Pflanzmethode, Silv meas für Waldbaumaßnahme, Plant mat für Pflanzmaterial, Pri prob für Größtes Problem, Ins Fu für Insekten/Schadpilze, Game d für Wildschaden, Silv ins für Unzureichende Waldbaumaßnahme, D für Gegen Trockenheit, F für Düngung, N für Gegen Nährstoffmangel, A für Wuchsbeschleunigung, SC für Gegen Bodenverdichtung, p für Vergangenheit, P für Gegenwart, F für Zukunft, 1 bedeutet sehr gering, 5 sehr hoch.

No	Region	n	Country	Ess asp 1	Ess asp 2	Pr pro 1	Pr pro 2	Dp	DP	DF	FNp	FNP	FNF	FAp	FAP	FAF	SCp	SCP	SCF
1	Boreal		FI	Mech SP	Pla meth	Ins Fu	Drought	3	3	3	2	2	2	1	1	1	1	1	1
2	Boreal		FI	Mech SP	Plant mat	Ins Fu	Game d	5	5	5	2	2	2	3	3	3	1	1	1
3	Boreal		FI	Mech SP	Plant mat	Game d	Ins Fu	na	na	na	na	na	na	na	na	na	na	na	na
4	Boreal	8	FI	Mech SP	Plant mat	Drought	Game d	na	na	na	na	na	na	na	na	na	na	na	na
5	Boreal		FI	Mech SP	Plant mat	Drought	Ins Fu	5	5	5	4	4	4	2	2	3	1	1	2
6	Boreal		FI	Silv meas	Mech SP	Ins Fu	Ins Fu	na	na	na	na	na	na	na	na	na	na	na	na
7	Boreal		NO	Mech SP	Silv meas	Ins Fu	Ins Fu	1	1	1	1	1	1	1	1	1	1	1	1
8	Boreal		NO	Silv meas	Mech SP	Drought	Game d	2	2	2	1	1	1	1	2	3	1	2	3
9	Atl		FR	Silv meas	Plant mat	Drought	Drought	5	5	5	1	1	1	1	1	1	5	5	5
10	Atl	3	FR	Mech SP	Silv meas	Drought	Silv ins	1	3	5	3	4	4	2	2	1	2	2	3
11	Atl		FR	Mech SP	Silv meas	Game d	Game d	5	5	5	4	4	3	3	3	3	5	5	5
12	Atl Med		IT	Mech SP	Mech SP	Drought	Ins Fu	3	3	4	4	2	3	4	2	5	2	4	5
13	Atl Med		IT	Silv meas	Pla meth	Drought	Drought	5	5	na	3	3	na	3	2	na	5	4	na
14	Atl Med		IT	Mech SP	Plant mat	Drought	Drought	4	4	5	2	2	2	2	2	2	4	4	5
15	Atl Med		IT	Plant mat	Silv meas	Game d	Drought	3	3	3	1	1	1	1	1	1	1	1	1
16	Atl Med		IT	Plant mat	Silv meas	Drought	Drought	5	5	5	4	4	4	5	3	3	1	1	1
17	Atl Med	12	IT	Plant mat	Silv meas	Silv ins	Silv ins	2	2	2	3	3	4	2	2	3	3	3	3
18	Atl Med		IT	Pla meth	Plant mat	Drought	Drought	3	3	4	3	3	3	1	1	1	4	4	4
19	Atl Med		IT	Silv meas	Mech SP	Drought	Drought	4	5	5	4	3	2	1	1	1	2	5	5
20	Atl Med		IT	Silv meas	Plant mat	Silv ins	Drought	3	3	3	2	2	2	1	1	1	1	1	1
21	Atl Med		IT	Silv meas	Mech SP	Drought	Drought	5	5	5	2	2	1	2	1	1	1	1	1
22	Atl Med		ES	Plant mat	Silv meas	Drought	Drought	na	5	5	na	2	1	na	3	2	na	4	4
23	Atl Med		ES	Mech SP	Plant mat	Drought	Drought	5	5	5	2	3	2	2	2	2	4	4	4
24	Atl Cont		AT	Plant mat	Silv meas	Drought	Drought	3	4	5	1	1	1	1	1	1	3	4	5
25	Atl Cont		AT	Mech SP	Mech SP	Drought	Drought	5	5	5	3	2	4	1	1	1	3	3	3
26	Atl Cont		AT	Silv Meas	Mech SP	Drought	Drought	4	4	5	1	1	2	1	1	1	3	3	3
27	Atl Cont		AT	Mech SP	Silv meas	Drought	Drought	3	5	5	1	1	2	1	1	2	3	4	4
28	Atl Cont		AT	Plant mat	Pla meth	Drought	Drought	2	3	4	1	1	1	1	1	1	4	4	4
29	Atl Cont	11	AT	Mech SP	Mech SP	Drought	Silv ins	3	5	5	na	na	na	na	na	na	na	na	na
30	Atl Cont		AT	Silv Meas	Mech SP	Game d	Silv ins	4	4	5	1	1	1	1	1	1	1	1	1
31	Atl Cont		AT	Pla meth	Silv meas	Game d	Game d	1	2	3	1	1	1	1	1	1	1	1	1
32	Atl Cont		AT	Plant mat	Pla meth	Drought	Drought	2	2	3	na	na	na	na	na	na	na	na	na
33	Atl Cont		AT	Plant mat	Pla meth	Drought	Drought	4	5	5	1	1	1	3	3	3	4	5	5
34	Atl Cont		AT	Silv meas	Plant mat	Silv ins	Drought	3	3	4	na	na	na	na	na	na	5	5	5
35	Cont		BG	Silv meas	Mech SP	Drought	Drought	4	4	4	na	na	4	3	3	4	4	5	4
36	Cont		PL	Silv meas	Plant mat	Drought	Drought	3	4	4	2	3	2	1	1	1	4	5	4
37	Cont		PL	Mech SP	Silv meas	Drought	Game d	5	5	5	2	2	2	1	1	1	3	3	3
38	Cont		PL	Mech SP	Silv meas	Drought	Drought	na	na	na	na	na	na	na	na	na	na	na	na
39	Cont	9	PL	Mech SP	Pla meth	Drought	Drought	4	4	4	1	1	1	1	1	1	3	3	3
40	Cont		PL	Silv meas	Silv meas	Drought	Drought	1	1	5	1	1	1	1	1	1	1	1	1
41	Cont		SK	Silv meas	Mech SP	Drought	Game d	4	5	5	2	2	2	1	1	1	5	4	4
42	Cont		HU	Plant mat	Silv meas	Drought	Drought	3	3	3	1	2	2	1	2	2	4	4	4
43	Cont		HU	Silv meas	Plant mat	Drought	Game d	2	2	3	1	1	1	1	1	1	2	2	4

3 Results

In total, 65 potential respondents were contacted 43 of whom filled out the questionnaire. Table 2 offers an overview of the characteristics of the survey respondents and the answers to questions one and two (two entries per respondent, columns 4 to 7 respectively) and to question three (containing ordinal values from one to five in columns 8-19).

3.1 Most relevant aspects and threats at the establishment phase

The questions about the most relevant aspects (research question one) and threats (research question two) obtained a wide range of answers, eventually grouped into nine large main categories (Table 3). Five categories grouped the answers to question one (aspects), namely: mechanical site preparation, irrigation, plant material, planting method, and silviculture. Four categories grouped the answers to question two (threats) as follows: drought, insects/fungi, game damage, and insufficient silviculture. The preferences for the analyses have been counted as follows. Since two entries per survey were taken into account (see the explanation above) and 43 surveys were filled, in total 86 answers for each research question are available. For the amelioration of site conditions 28 votes were counted, 24 of which included mechanical site preparation, and 4 referred to irrigation. Out of the first 24, 16 referred to soil preparation as the main purpose of mechanical site preparation, and 8 to weed control as its principal scope. And finally, according to 23 out of these 24 votes, the referenced measure represents a sustainable way for the provision of water or/and nutrients, respectively. All remaining category-specific information provided by Table 3 are interpreted in a similar manner.

Table 3: Reduction of the survey answers to sub-categories (cursive) and main categories (in bold). Between brackets the numbers of respondents are inserted. The numbers in bold (23, 18, 7, 24) denote the surveys where the respective measure is characterized as sustainable method for water or/and nutrient supply.

Tabelle 3: Zusammenfassung der Fragebogenantworten zu Unterkategorien (kursiv) und Hauptkategorien (fettgedruckt). Zwischen Klammern ist die jeweilige Anzahl an Fragebögen angegeben. Die fettgedruckten Zahlen (23, 18, 7, 24) bezeichnen die Anzahl an Fragebögen, in denen eine jeweils genannte Maßnahme als nachhaltige Methode zur Wasser und/oder Nährstoffversorgung dargestellt ist.

Research question	Subcategories of the answers	Main categories of the answers
Question 1: Essential aspects at stand establishment?	- *Soil preparation* (16) disc-trenching, harrowing, subsoiling, rotovating, soil inversion, patch mounding, ditch mounding, drainage, micro catchments, retention and infiltration ditches... - *Mechanized weed control/mulching* (8) - *Irrigation* (4)	**Mechanical site preparation** (24/**23**) (Amelioration of site conditions) **Irrigation (4)** (Amelioration of site conditions)
	Right plant material (seedlings, clones, seeds)	**Plant material** (20/**18**)
	Right planting method, preparation and storage of seedlings, clones, seeds...	**Planting method** (9/**7**)
	- *Regeneration method* (e.g. choice of appropriate site, generation of good site conditions by cutting system...) (6) - *Choice of tree species/clones* (8) - *Tree species mixture* (1) - *Spacing* (1) - *Cleaning, tending* (3) - *Right timing* of planting and further work steps, e.g. planting in autumn or fall, ploughing in autumn or fall... (10)	**Silviculture** (29/**24**)
Question 2: Greatest problems at stand establishment?	- *Drought* (57)	**Drought** (57)
	- *Insects / Fungi* (9)	**Insects / Fungi** (9)
	- *Game damage* (13)	**Game damage** (13)
	- *Competing vegetation* (3) - *Soil degradation* (1) - *Soil compaction* (1) - *Invasive species* (1) - *Seed shortage/poor seed quality* (1)	**Silvicultural insufficiency** (7)

Drought emerged as the most severe threat to stand establishment, since it was mentioned by 66% (57 out of 86) of the experts (Table 3). However, irrigation (its essential countermeasure) only scored four votes. Most respondents (*i.e.*, 84% or 72 out of 86) indicated silviculture (24), mechanical site preparation (23) plant material (18), and planting method (7) as the most beneficial measures when establishing a stand, and at the same time identified them as sustainable methods for the provision of water or/and nutrients (Table 3).

The distribution of votes differed significantly among regions (Figures 1A, 1B). When regional distributions were analysed, Pearson's Chi square Test yielded a $p < 0.001$ for question one (Figure 1A) and $p < 0.001$ for question two (Figure 1B), respectively.

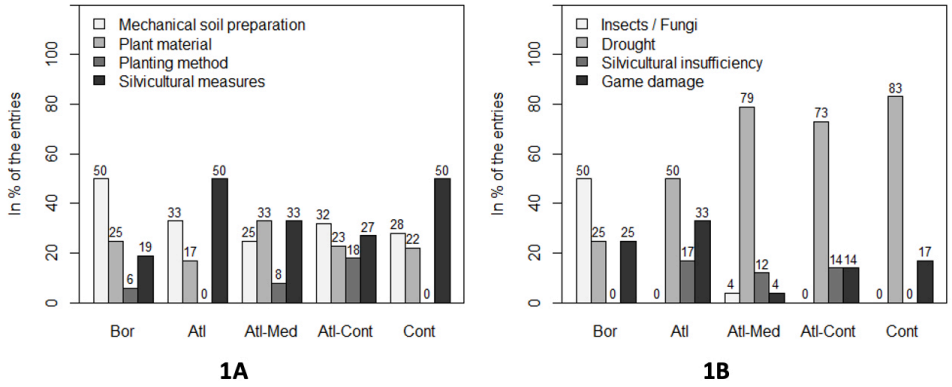

Figure 1: Region-specific illustration of the responses given to the research questions on the key aspects (1A), and the biggest problems (1B) at the stand establishment. The bars represent the percentages of the entries for each of the four assessed categories of measures. For a more detailed description of the categories please refer to Table 3.

Abbildung 1: Darstellung der Fragebogenantworten gemäß Regionen zur Frage nach den Schlüsselfaktoren (1A) und den Risikofaktoren (1B) bei Bestandesbegründung. Die Balken stellen die vier Maßnahmenkategorien in Prozent der Gesamtanzahl der Antworten für eine jeweilige Region dar. Eine detaillierte Beschreibung der Kategorien findet sich in Tabelle 3.

For the boreal region, the two fundamental aspects of stand establishment are mechanical site preparation and plant material. The most detrimental factor is insects/fungi. In contrast, in all other parts of Europe, silvicultural measures, followed by mechanical site preparation, are considered most essential for a successful stand establishment, and drought is considered the most detrimental factor, followed by game damage (Figures 1A, 1B).

3.2 Expected relevance of measures in the future

Research question three targeted to assess the urgency of *measures against drought, fertilization activities, measures against soil compaction*, and eventually *other measures* (see the survey in the supplementary material) from the view of the experts. The aspect other measures was scarcely answered (23 respondents completed this part of the questionnaire out of 43, and only one entry was available for some of the five regions), therefore a statistical evaluation for other measures was not feasible. Figure 2A provides a region-wise illustration of future urgencies of the above-listed measures according to the experts. Figure 2A concentrates on the contrast between the urgencies in the future and in the past, again, according to the regions and the estimations of the experts.

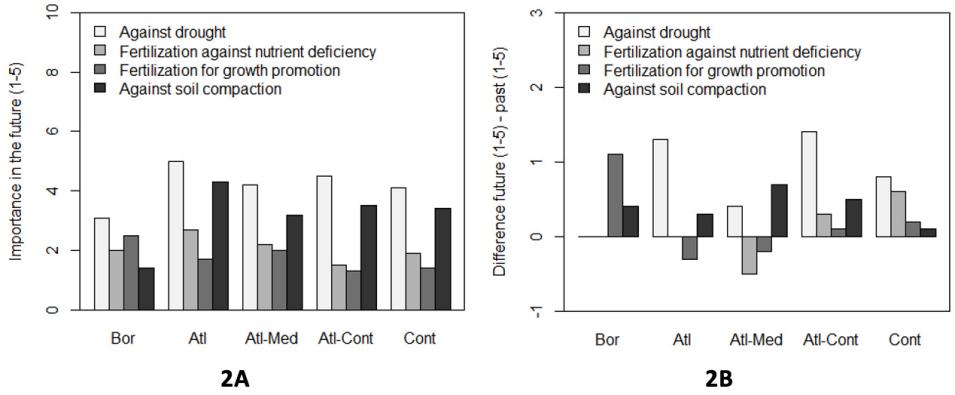

Figure 2: Importance of the listed four measures in the future according to biogeographic regions (2A). Change of importance of the measures (future compared to past) according to biogeographic regions (2B).

Abbildung 2: Bedeutung der in der Abbildung genannten vier Maßnahmen in der Zukunft, getrennt für alle biogeografischen Regionen (2A). Veränderung der Bedeutung der Maßnahmen (Zukunft minus Vergangenheit), getrennt für alle biogeografischen Regionen (2B).

In all regions measures against drought are expected to become the most important in the future (Figure 2A). When the future was compared with the past (Figure 2B), the importance of fertilization promoting growth is expected to increase significantly in the boreal region, while in all other regions the largest increase is expected for measures against drought and measures against soil compaction.

A Kruskal Wallis test and a Dunn test confirmed the statistical significance of the differences for measures *against drought* (p-value of 0.003), for *fertilization in favour of accelerating growth* (p-value of 0.016), and for measures *against soil compaction* (p-value of 0.015) (Table S1 in the supplementary material). Furthermore, significant differences were found to occur mainly in pairings where the Boreal region is represented, suggesting that different trends are present between the Boreal region on the one hand and all other regions on the other hand (Table S1 in the supplementary material).

3.3 Identifying biogeographic clusters for early measures

Occurring similarities and dissimilarities in stand establishment practices between the regions are further illustrated and analyzed by two visualization techniques. The nmds algorithm depicts the 43 observations (Table 2) in a multidimensional space

for which five dimensions were specified. The integrated convex hulls delineate the minimum areas of each of the biogeographic regions and make these regions evident. The PAM cluster analysis arranges the same 43 observations around the centers of the defined number of clusters. In our case, two clusters have been set since the respective value of Silhouette width for two clusters is the highest. The results of the two visualization procedures are illustrated in Figures 3A and 3B.

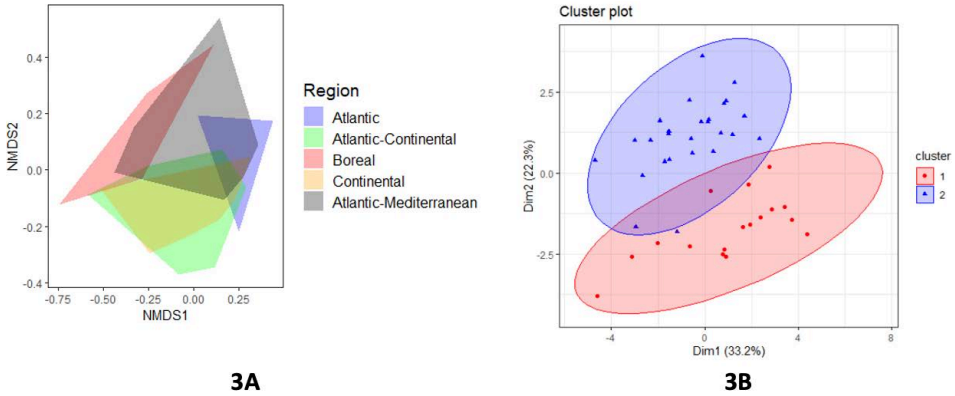

Figure 3: Visualization of the dissimilarities in stand establishment practices between the biogeographic regions by nmds plot (3A). Result of the custer analysis on similarities and dissimilarities in stand establishment practices under the assumption of two clusters (3B).

Abbildung 3: Visualisierung der Unterschiede in den Bestandesbegründungspraktiken zwischen den biogeographischen Regionen gemäß nmds Plot (3A). Ergebnis der Clusteranalyse zu den Gemeinsamkeiten und Unterschieden betreffend Bestandesbegründungspraktiken unter der Annahme von zwei Clustern (3B).

The Kruskal stress type 1 as an estimate for the accuracy of the nmds plot (Figure 3A), is 0.04 which signifies a good fit between the plotted and the real values/surveys. According to Figure 3A, Boreal ranges apart from most of the other regions, only with Atlantic-Mediterranean it has a strong overlapping. Continental and Atlantic-Continental to large extent cover the same area. Atlantic ranges far away from Boreal and rather tends to overlap with the two continental regions. The mediterranean region to noticeable extent covers the area between the boreal zone and the continental zone. The goodness of fit of the cluster model (Figure 3B) as quantified by the Silhouette coefficient is 0.15 for cluster one, 0.27 for cluster two, and 0.36 for the total model (see Table S2 in supplementary material), signifying a weak structure. Even so, it is evident from Figure 3B that the two outlined clusters are well differentiated with only two observations (surveys) ranging in the intersection zone. To interpret the abstract cluster landscape against the background of the real biogeographic regions, the re-

sults of the cluster landscape from Fig. 3B are linked with the biogeographic regions in Table 4.

Table 4: Linkage of the cluster landscape from Figure 3B with the biogeographic regions. The highlighted numbers denote the members of cluster one, all others belong to cluster two. The numbers in bold represent the medoids (centres) of the clusters.

Tabelle 4: Zuordnung der Clusterelemente von Abbildung 3B zu den jeweiligen biogeografischen Regionen. Die grau hinterlegten Felder dienen als Hervorhebung der Elemente, die zu Cluster eins gehören, alle anderen genannten Fragebögen gehören zu Cluster zwei. Die fettgedruckten Zahlen bezeichnen die Medoide (Zentren) der Cluster.

Survey no.	*Region*	*Cl*	*Survey no.*	*Region*	*Cl*
1	Boreal	1	24	Atlantic-Continental	2
2	Boreal	1	25	Atlantic-Continental	2
3	Boreal	1	26	Atlantic-Continental	2
4	Boreal	1	27	Atlantic-Continental	2
5	Boreal	1	28	Atlantic-Continental	2
6	Boreal	1	29	Atlantic-Continental	2
7	Boreal	1	30	Atlantic-Continental	1
8	Boreal	1	31	Atlantic-Continental	1
9	Atlantic	2	32	Atlantic-Continental	2
10	Atlantic	1	33	Atlantic-Continental	2
11	Atlantic	2	34	Atlantic-Continental	2
12	Atlantic-Medit	2	35	Continental	2
13	Atlantic-Medit	2	36	Continental	2
14	Atlantic-Medit	2	37	Continental	2
15	Atlantic-Medit	1	**38**	Continental	2
16	Atlantic-Medit	1	39	Continental	2
17	Atlantic-Medit	1	40	Continental	1
18	Atlantic-Medit	2	41	Continental	2
19	Atlantic-Medit	2	42	Continental	2
20	Atlantic-Medit	1	43	Continental	2
21	Atlantic-Medit	1			
22	Atlantic-Medit	2			
23	Atlantic-Medit	2			

Out of the 43 filled surveys, 17 belong to cluster one and 26 to cluster two. All representatives of the boreal region belong to cluster one. Atlantic-Mediterranean seems to be an intermediate region with a strong representation in cluster one (five surveys, see Table 4). Still, the majority of its elements belong to cluster two. Both Atlantic-Continental as well as Continental predominantly represent cluster two. This way, the results of the cluster analysis (Figure 3B, Table 4) are consistent with the outcomes of the nmds plotting (Figure 3A).

The described limitations notwithstanding, in the following sections we go along with the result of the cluster analysis and assume two clusters: a so-called *boreal clus-*

ter on the one hand, and a *European mainland cluster* on the other hand. The medoid (center) of the boreal cluster is represented by survey 4, the medoid of the European mainland cluster by the survey 38. The medoids express the main properties of the clusters, according to the PAM clustering method (Table 5).

Table 5: Characteristics of the medoids (centres) of the two clusters. Cl stands for Cluster, Ess asp for Essential aspect, Mech SP for Mechanical site preparation, Plant mat for Plant material, Silv meas for Silvicultural measures, Pr pro for Principal problem, Game d for Game damages, D for Against drought, F for Fertilization, N for Against nutrient deficiency, A for Promoting growth, SC for Against soil compaction, p for past, P for present, F for future, 1 means low, 5 very high.

Tabelle 5: Charakteristika der Medoide (Zentren) der beiden Cluster. Cl steht für Cluster, Ess asp für Entscheidender Punkt, Mech SP für Mechanische Bodenvorbereitung, Plant mat für Pflanzmaterial, Silv meas für Waldbaumaßnahme, Pr pro für Größtes Problem, Game d für Wildschaden, D für Gegen Trockenheit, F für Düngung, N für Gegen Nährstoffmangel, A für Wuchsbeschleunigung, SC für Gegen Bodenverdichtung, p für Vergangenheit, P für Gegenwart, F für Zukunft, 1 bedeutet sehr gering, 5 sehr hoch.

Medoid (center of clusters) characteristics																	
Cl	**No**	**Ess asp 1**	**Ess asp 2**	**Pr pro 1**	**Pr pro 2**	**Dp**	**DP**	**DF**	**FNp**	**FNP**	**FNF**	**FAp**	**FAP**	**FAF**	**SCp**	**SCP**	**SCF**
1	**4**	Mech SP	Plant mat	Drought	Game d	3	3	3	2	2	2	1	2	3	1	1	1
2	**38**	Mech SP	Silv meas	Drought	Drought	4	4	4	1	2	2	1	1	1	4	4	4

For cluster one (boreal cluster with its medoid in survey no. 4) the most important measures are mechanical site preparation and plant material, while the most severe problems are drought and game damage. Conversely, for cluster two (European mainland cluster with medoid in survey no.38) mechanical site preparation and silvicultural measures are the most important measures and drought the most severe problem.

4 Discussion

4.1 The main categories of establishment measures and threats to cope with

This study concentrated on the measures for successful establishment of forest crops and looked for similarities and/or differences between five biogeographic ecoregions (Boreal, Atlantic, Atlantic-Mediterranean, Atlantic-Continental, and Continental) in Europe. Data collection was carried out by a questionnaire survey. For the quantitative evaluation of the results of the survey on the most important measures at the establishment phase and the obstacles during the establishment, the variety of answers provided by the respondents were condensed to four categories including

mechanical site preparation, plant material, correct planting, and silvicultural measures as salient aspects for successful stand establishment, and drought, insects/fungi, game damage, inadequate silvicultural strategies as most severe problems at stand establishment.

The overwhelming majority of the experts qualified the measures for successful stand establishment as sustainable strategies to face water or/and nutrient shortages. An equally large majority pointed at drought as the most severe future threat (Table 3). Experts also indicated that irrigation is currently just a secondary measure to overcome water scarcity: much more importance is attributed to silvicultural strategies (*i.e.*, right timing of planting, choice of tree species, and regeneration/cutting method), immediately followed by mechanical site preparation (Table 3). Nevertheless, financial support from the government or other sources for investments in irrigation (e.g., irrigation facilities, storage reservoirs for irrigation purposes) could influence that view and affect future strategies.

4.2 Priorities of stand establishment measures in the different biogeographic regions

In answer to the research questions one and two, the study found that mechanical site preparation and plant material are the most important measures for the boreal area (Figure 1A, Table 5). A preference for the plant material (*nurseries and tree breeding*) of the boreal biome as a distinctive feature was also found by (Kolström *et al.*, 2011) who scrutinized all climate change adaptation measures in forestry, based on the same European regions as adopted for the present study. In all other regions *i.e.* the European mainland regions, more importance is attached to silvicultural measures, followed again by mechanical site preparation (Figure 1A, Table 5), according to the here achieved results. When addressing the most urgent threats, insects and fungi raise the highest concern in the Boreal region, while game damage and drought are especially alarming in the other European regions (Figure 1B, Table 5). The boreal concern with insects and fungi likely reflects the current pine weevil (*Hylobius abietis L.*) infestation that is hitting the Scandinavian forests, favoured by the monospecific character of the stands in that area that nowadays are largely reforested by planting (Lalik *et al.*, 2021). Low tree species diversity in general, and specifically the small number of tree species used in the Nordic countries (Official Statistics of Finland, 2022) might decrease biodiversity, which is conducive to the mass spread of pests (Lundgren & Fausti, 2015). Conversely, in mainland Europe, drought is considered the main problem, followed by game damage (Figure 1B, Table 5). A further difference between the boreal region and mainland Europe is that respondents from the former area do not consider silviculture deficits to be a problem, while those from the latter one do consider it as an important issue (Figure 1).

When concentrating on the quantitative assessment of how significant measures are expected to be in the future according to the experts, especially when compared to the past (research question three), three measures are found to be different among the European regions at the selected significance level, and namely: measures against soil compaction, measures against drought, and fertilizing for growth acceleration (Table 1S supplementary material). Measures against drought will play a dominant role in the future in all regions, but their relevance will increase much more in mainland Europe than in the Boreal region (Figure 2B). Similarly, activities against soil compaction will become more relevant in mainland Europe than in the Boreal region. The most likely reason for that difference is that mechanical site preparation is already common in the boreal region, and therefore its application is not expected to increase as much as in mainland Europe, where mechanical site preparation is still relatively uncommon. That is not to say that its use will not increase in the Boreal region as well, and figure 2B shows that such increase will occur: it is just that its expected increase is not as large as estimated for mainland Europe.

Moreover, in the boreal region, great emphasis is placed on fertilization for growth acceleration (Figure 2B, Table 5), which is in significant contrast to mainland Europe (Table 4, Table 5) where fertilization is expected to be even less of importance than in the past (Figure 2B). When accomplished at the time of the planting or immediately after, fertilization is beneficial for tree growth and stem quality, depending on the involved tree species, the planting methods and the growth region (Marshall *et al.*, 2022; Smethurst, 2010). The basic understanding of fertilization refers to its application at the stand establishment (Smethurst, 2010). However, when directing the focus on a mere economic profitability, it is more viable to apply fertilization at a later stage of the stand development *e.g.* in the pole stage wood to shorten the time lag between the investment and the final harvest (Pukkala, 2017). By nature, the firstly listed understanding of the term (fertilization at stand establishment) was valid for the present study since it deals with *early measures at stand establishment*. In the Scandinavian countries fertilization practices, after introduction and widespread application in the 1960s gradually came out of fashion. Only over the recent years the interest has been increasing again (Lindkvist *et al.*, 2011). The positive expectations towards fertilization from the side of the practicioners of this region, might be motivated by the fact that in both boreal countries taken into consideration by the survey (*i.e.* Finland and Norway) the use of fertilizers to accelerate growth is encouraged by the respective governments as a way to increase CO2 storage through faster trees growth. Both countries, therefore, have great confidence in this measure as part of their climate change mitigation strategy (see forest.fi, 2020).

The results of a Dunn test concerning fertilization for enhancing growth disclose the boreal region being present in all pairs where significant differences are detected (Table 1S in supplementary material). Thus, the difference between Boreal and the rest of the regions in this respect is statistically substantiated. In total, when considering the measures against soil compaction, those against drought, and those for

fertilization, the pairwise comparison by the Dunn test shows that Boreal is present in eight out of nine differing pairings (Table 1S in supplementary material). In outline, an exceptional position of Boreal in contrast to all other European biomes also reflects from (Kolström *et al.*, 2011): In this study, in four out of eight assessed categories of adaptation measures against climate change, Boreal markedly differs from the other regions. The identified distinction has bearing on the assumption of two clusters as will be discussed in the in the next paragraph.

4.3 The two clusters in stand establishment practices in Europe

In the before-said, two rather homogeneous regions became apparent, a boreal region and an area complecting the European mainland countries. Research question four explicitly raised the question about a grouping of the European regions in the context of measures for stand establishment. A cluster analysis conducted to this end evidenced, in outlines, two graphically distinguishable clusters (Figure 3B), the here so-called boreal cluster and the European mainland cluster. Since the boreal cluster as delineated by the cluster analysis, comprises elements that pertain to regions other than Boreal (Table 4), and since the associated accuracy coefficient points at a relatively weak cluster model (Table 2S in supplementary material), this distinction admittedly is carried by some abstraction and generalization. Even so, it was adopted out of the following considerations: Firstly, all surveys of the boreal region without exception range within one and the same cluster (cluster one). Secondly, the result of the cluster analysis is not interpreted in isolation but in conjunction with the above-presented statistical evaluations in the context of research question three (Table 1S in supplementary material), that clearly suggest that a difference between the boreal region on the one hand and all other European regions on the other hand, is given. Thirdly, the conformity of both approaches (the analyses to research question three, and the cluster analysis) is corroborated by the fact that the information contained by the medoids (which are a component of the performed cluster analysis) (Table 5) finds a clear correspondence in the (above debated) messages reflecting from the Figures 1A,B and 2A,B.

4.4 Interpretation of the identified stand establishment priorities in the context of climate change

According to the European Environment Agency (EEA, 2017) some far-reching trends as a result of climate change are to be expected for the European biogeographic regions. The corresponding main trajectories of relevance for this study, are: the boreal region will experience a *temperature rise*, an *increase in precipitation*, a *northward movement of species*, and an *increasing potential for forest growth and increasing risk of*

forest pests, the continental region will face an *increase in heat extremes*, an *increase in risk of forest fire*, and a *decrease in summer precipitation*, the atlantic part of Europe will be confronted with an *increasing winter precipitation* and an *increasing damage risk from winter storms*, and the mediterranean countries will undergo an *increase in heat extremes*, an *increase in risk of droughts*, of *forest fires* and *desertification*, an *increase in risk of biodiversity loss*, and a *decrease in precipitation*.

The increasing *risk of forest pests* as predicted by the EEA report for the boreal region, finds a direct correspondence in the results of this study (Figure 1B). However, the most positive scenario is predicted for the boreal biome, as can be extracted from the before-referred statements. The expected *northward migration of tree species* in combination with the *increasing potential for forest growth*, might partly explain the efforts to improve the genetic stock in the boreal region (Figure 1A). An enlargement of the potential tree species pool by highly prospecting candidates such as Douglas-fir, Sitka spruce, lodgepole pine, and different poplars (Haapanen *et al.*, 2015), opens new possibilities for forestry. Though, the growth, the growth rhythm, and especially the flowering phenology of trees are determined not only by the water availability and the temperature but also by the phototrophic conditions of a region of interest (*e.g.* the night length governing the bud set *etc.*), which is much of importance for the performance of young trees in a non-domestic environment (Hannerz, 1998). In addition, various types of pests and pathogens might appear and compromise the success of introduced tree species (Yanchuk *et al.*, 2009). In this light, the need to elaborate much on the generation of approriate plant material as expressed by the practicioners of the boreal region, is better understandable.

In all other bioclimatic regions *i.e.* the here so-called European mainland regions, the negative expectations prevail, according to the EEA report. The most pressing scenarios are the *rise of temperature* and the *decline in precipitation* during the vegetation period, as can be seen from the assertions referred above. In this view, the statements of the experts of the European mainland are also better traceable since in their opinion the aspect of utmost importance is drought and the corresponding countermeasures. First of all, this holds true for the *warm mediterranean region* where drought periods by definition occur regularly, according to the Köppen-Geiger climate map (Peel *et al.*, 2007). Still, it is also valid for the other European mainland regions, according to the here achieved results (Figure 1B, Figure 2). To this must be added that the techniques for site preparation and against soil compaction which play a key role for the experts of these regions, overwhelmingly are seen as sustainable measures to face drought (Table 3). The more so, measures out of the category *silviculture* that are fundamental for the stand establishment in the eyes of the experts of these regions (Figure 1), nowadays play a key role in the fight against risks as contained by the EEA report and listed above (storm, pests, and biodeversity loss) (*e.g.* Tognetti *et al.*, 2022). The term *silviculture* in this connection might be considered just a synonym for the expression *climate smart forestry* which aims to build resilient forest ecosystems (Nabuurs *et al.*, 2018). Also with respect to the found relevance of silvicultural

measures, therefore, the results of the study mirror the conditions and constraints that climate change has generated in the forests of the European continent.

Ultimately, the experts consulted for this study identified three groups of measures for stand establishment, which constitute the very core of the forestry strategies devised to face climate change: plant material selection, site preparation, and silviculture. To a large extent, this is in agreement with the suggestions outlined in (Forest Europe, 2020b). That report clearly states that "the best opportunity to enhance the adaptive capacity of forests is during a regeneration period (…) and in the early stand-development stages" (p. 34). In the context of the cited report, the strongest focus is on plant material. In that respect, concrete measures cover: the choice of tree species, genotypes, and provenances; the introduction of new species (non-natives); and the managed relocation of native species i.e. the so-called assisted migration (Williams & Dumroese, 2013). Secondly, that report points to the importance of provisioning water to the stands. As essential sub-strategies leading to this goal, it does promote irrigation methods (*e.g.* the building and restoring of small water reservoirs) but shows a clear preference for more sustainable alternatives. As such, it recommends specific measures within site preparation (*e.g.* weeding) and silviculture (*e.g.* suitable tree species combination). Our study fully agrees with those strategies by zooming in on the specific measures to be taken at the early development stage (*i.e.* plantation and establishment).

5 Conclusion

The evaluations of the survey on forest stand establishment practices in Europe led to the distinction of two regions: Boreal and mainland Europe. For the boreal region, most attention is on *mechanical site preparation*, followed by *plant material*. The most severe threat for this biogeographical context comes from the *insects*, and *fertilization for growth acceleration* is expected to be the most promising measure in the future compared to the past. Experts from mainland Europe, rate *silvicultural measures* as most important for successful reforestation, followed by *mechanical site preparation*. Here, the principal threat is seen in drought, followed by *game damage*. Measures *against drought and against soil compaction*, are considered as most beneficial for the stand establishment in the future. In all regions the listed key aspects for stand establishment overwhelmingly are seen as effective sustainable measures for the water procurement.

Based on these results, three guidelines for the future practice are expressed:

i) The most relevant threat in the future is drought.
ii) The most promising countermeasure against drought is not irrigation but
iii) rather any of the following techniques for sustainably increasing water use efficiency and availability, such as mechanical site preparation, appropriate plant material, and silvicultural strategies.

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Supplementary material

Table S1 shows the results of the Kruskal Wallis-test and the Dunn test on the differences between the biogeographic regions in terms of the importance that by the experts is attributed to the listed early measures for stand establishment in

i) the future and
ii) the future in contrast to the past.

Table S2 contains the Silhouette coefficients as measures for the goodness of clustering.

The original version of the survey is also included in the supplementary material.

Conflict of interest statement

The authors declare no conflict of interest.

Author Contributions

Conceptualization, B.E., M.vL.; data collection, B.E., S.B., K.B., T.L., C.O., R.S., M.vL; methodology, 412 B.E., M.vL; software and analyses, B.E., writing – original draft preparation, B.E., M.vL, S.B., K.B., T.L., C.O., writing – 413 review and editing, B.E., S.B., K.B., T.L., C.O., R.S., M.vL; supervision, M.vL, funding acquisition, M.vL.

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References

Aleksandrowicz-Trzcinska, M., Drozdowski, S., Ligocki, M., & Zybura, H. (2017). Wpływ sposobu przygotowania gleby na cechy odnowienia naturalnego sosny zwyczajnej (*Pinus sylvestris L.*) w Nadleśnictwie Spychowo. Sylwan, 161(03).

Aleksandrowicz-Trzcińska, M., Drozdowski, S., Ligocki, M., Żybura, H., & others. (2017). Effect of mechanical site preparation methods on characteristics of the natural regeneration of Scots pine (*Pinus sylvestris L.*) in Spychowo forest district. Sylwan, 161(3), 196–207.

Alia, R., Aravanopoulos, F., Fjellstad Kjersti Bakkebøand Bozzano, M., Fady, B., Gonzalez-Martinez, S. C., Heinze, B., Kandemir, G., Kozioł, C., Kraigher, H., & others. (2021). Forest genetic resources strategy for Europe. EUFORGEN.

Ammer, C., Balandier, P., Bentsen, N. S., Coll, L., & Löf, M. (2011). Forest vegetation management under debate: an introduction. In European Journal of Forest Research (Vol. 130, pp. 1–5). Springer.

Anderson, J. A., Long, A., & Luckert, M. K. (2015). A financial analysis of establishing poplar plantations for carbon offsets using Alberta and British Columbia s afforestation protocols. Canadian Journal of Forest Research, 45(2), 207–216.

Auzuret, X., Gibaud, G., Piat, J., Collet, C., Wehrlen, L., Richter, C., Girard, Q., & Fraysse, J.-Y. (2014). Contrôler la fougère aigle sans asulame: quelles méthodes alternatives pour réussir les plantations? Rendez-Vous Techniques de l'ONF, 43, p--22.

Bird, D. K. (2009). The use of questionnaires for acquiring information on public perception of natural hazards and risk mitigation – a review of current knowledge and practice. Natural Hazards and Earth System Sciences, 9(4), 1307–1325.

Böhlenius, H., & Övergaard, R. (2015). Exploration of optimal agricultural practices and seedling types for establishing poplar plantations. Forests, 6(8), 2785–2798.

Borg, I., & Groenen, P. J. F. (2005). Modern multidimensional scaling: Theory and applications. Springer Science & Business Media.

Brancato, G., Macchia, S., Murgia, M., Signore, M., Simeoni, G., Blanke, K., & Hoffmeyer-Zlotnik, J. (2006). Handbook of recommended practices for questionnaire development and testing in the European statistical system. European Statistical System.

Cervellini, M., Zannini, P., Di Musciano, M., Fattorini, S., Jiménez-Alfaro, B., Rocchini, D., Field, R., Vetaas, O. R., Irl, S. D. H., Beierkuhnlein, C., & others. (2020). A grid-based map for the Biogeographical Regions of Europe. Biodiversity Data Journal, 8.

Cortina, J., Amat, B., Castillo, V., Fuentes, D., Maestre, F. T., Padilla, F. M., & Rojo, L. (2011). The restoration of vegetation cover in the semi-arid Iberian southeast. Journal of Arid Environments, 75(12), 1377–1384.

Cortina, J., Bellot, J., Vilagrosa, A., Caturla Cardona, R. N., Maestre, F. T., Rubio, E., de Urbina, J. M., Bonet, A., & others. (2004). Restauración en semiárido. Capitulo 12, En" Avances En El Estudio de La Gestión Del Monte Mediterráneo", En Vallejo, RV, y Alloza, JA (Eds.). Pag. 345-406.

Coyle, D. R., & Coleman, M. D. (2005). Forest production responses to irrigation and fertilization are not explained by shifts in allocation. Forest Ecology and Management, 208(1–3), 137–152.

del Campo, A. D., Segura-Orenga, G., Ceacero, C. J., González-Sanchis, M., Molina, A. J., Reyna, S., & Hermoso, J. (2020). Reforesting drylands under novel climates with extreme drought filters: The importance of trait-based species selection. Forest Ecology and Management, 467, 118156.

EEA (2017). Climate change, impacts and vulnerability in Europe 2016 — An indicator based report. EEA Report No 1/2017, European Environment Agency, https://www.eea.europa.eu/publications/climate-change-impactsand-vulnerability-2016

FOREST EUROPE (2020a). State of Europe´s forests 2020.

FOREST EUROPE (2020b). Adaptation to Climate Change in Sustainable Forest Management in Europe. Liaison Unit Bratislava, Zvolen, 2020.

FAO (2020). Global Forest Resources Assessment 2020: Main Report. Rome.

Fiala, M., Bacenetti, J., Scaeavonati, A., & Bergonzi, A. (2010). Short rotation coppice in northern Italy: comprehensive sustainability. European Biomass Conference and Exhibition, 343–348.

Galbraith, J. I., Moustaki, I., Bartholomew, D. J., & Steele, F. (2002). The analysis and interpretation of multivariate data for social scientists. Chapman and Hall/CRC.

Geiger, R. (1961). Überarbeitete Neuausgabe von Geiger, R. Köppen-Geiger/Klima Der Erde.(Wandkarte 1: 16 Mill.) – Klett-Perthes, Gotha.

Haapanen, M., Jansson, G., Nielsen, U. B., Steffenrem, A., & Stener, L. G. (2015). The status of tree breeding and its potential for improving biomass production – a review of breeding activities and genetic gains in Scandinavia and Finland. Skogforsk, Uppsala.

Hannerz, M. (1998). Genetic and seasonal variation in hardiness and growth rhythm in boreal and temperate conifers. Report No 2: 1-140. Skogforsk.

Kaufman, L., & Rousseeuw, P. J. (2009). Finding groups in data: an introduction to cluster analysis. John Wiley & Sons.

Kolström, M., Lindner, M., Vilén, T., Maroschek, M., Seidl, R., Lexer, M. J., Netherer, S., Kremer, A., Delzon, S., & Barbati, A. (2011). Reviewing the science and implementation of climate change adaptation measures in European forestry [JOUR]. Forests, 2(4), 961–982.

Kruskal, J. B., & Wish, M. (1978). Multidimensional scaling. Series: Qualitative Applications in the Social Sciences (Issue 11). Sage Publications Inc., Thousand Oaks, CA, USA.

Kruskal, W. H., & Wallis, W. A. (1952). Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association, 47(260), 583–621.

Lalik, M., Galko, J., Kunca, A., Nikolov, C., Rell, S., Zúbrik, M., Dubec, M., Vakula, J., Gubka, A., Leontovyč, R., & others. (2021). Ecology, management and damage by the large pine weevil (Coleoptera: Curculionidae) in coniferous forests within Europe. Central European Forestry Journal, 67(2), 91–107.

Lindkvist, A., Kardell, Ö., & Nordlund, C. (2011). Intensive forestry as progress or decay? An analysis of the debate about forest fertilization in Sweden, 1960--2010. Forests, 2(1), 112–146.

Lobet, G., Couvreur, V., Meunier, F., Javaux, M., & Draye, X. (2014). Plant water uptake in drying soils. Plant Physiology, 164(4), 1619–1627.

Löf, M. (2000). Influence of patch scarification and insect herbivory on growth and survival in *Fagus sylvatica L.*, *Picea abies L. Karst.* and *Quercus robur L.* seedlings following a Norway spruce forest. Forest Ecology and Management, 134(1–3), 111–123.

Löf, M., Dey, D. C., Navarro, R. M., & Jacobs, D. F. (2012). Mechanical site preparation for forest restoration. New Forests, 43(5), 825–848.

Lowery, R. F., & Gjerstad, D. H. (1991). Chemical and mechanical site preparation. Forest Regeneration Manual, 251–261.

Lundgren, J. G., & Fausti, S. W. (2015). Trading biodiversity for pest problems. Science Advances, 1(6), e1500558.

Luoranen, J., & Viiri, H. (2021). Comparison of the planting success and risks of pine weevil damage on mineral soil and drained peatland sites three years after planting.

Lyr, H. (1996). Effect of the root temperature on growth parameters of various European tree species. Annales Des Sciences Forestières, 53(2–3), 317–323.

Marchi, M., Bergante, S., Ray, D., Barbetti, R., Facciotto, G., Chiarabaglio, P. M., Hynynen, J., & Nervo, G. (2022). Universal reaction norms for the sustainable cultivation of hybrid poplar clones under climate change in Italy. IForest-Biogeosciences and Forestry, 15(1), 47.

Marshall, A., Nelson, C. R., & Hall, J. S. (2022). Species selection and plantation management in enrichment planting with native timber species in the Panama Canal watershed. Frontiers in Forests and Global Change, 5, 925877.

Mc Carthy, R., Rytter, L., & Hjelm, K. (2017). Effects of soil preparation methods and plant types on the establishment of poplars on forest land. Annals of Forest Science, 74(2), 1–12.

Munson, A. D., Margolis, H. A., & Brand, D. G. (1993). Intensive silvicultural treatment: impacts on soil fertility and planted conifer response. Soil Science Society of America Journal, 57(1), 246–255.

Nabuurs, G.-J., Verkerk, P. J., Schelhaas, M., González-Olabarria, J. R., Trasobares, A., & Cienciala, E. (2018). Climate-Smart Forestry: mitigation implact in three European regions (Vol. 6). European Forest Institute.

Nermin, H., & Francesco, C. (2021). Evidence Emerging from the Survey on European Union Timber Regulation [REG.(EU) 995/2010] in Italy. Open Journal of Forestry, 12(1), 142–161.

Norby, R. J., & Jackson, R. B. (2000). Root dynamics and global change: seeking an ecosystem perspective. The New Phytologist, 147(1), 3–12.

Official Statistics of Finland. (2022). Finland – Current Climate – Climatology. https://www.luke.fi/en/statistics/silvicultural-and-forest-improvement-work, date accessed 22.11.2022

Orazio, C., Freer-Smith, P., Payn, T., & Fox, T. (2019). Species choice, planting and establishment in temperate and boreal forests: meeting the challenge of global change. In Achieving sustainable management of boreal and temperate forests (pp. 397–412). Burleigh Dodds Science Publishing.

Padilla, F. M., & Pugnaire, F. I. (2006). The role of nurse plants in the restoration of degraded environments. Frontiers in Ecology and the Environment, 4(4), 196–202.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11(5), 1633–1644.

Pukkala, T. (2017). Optimal nitrogen fertilization of boreal conifer forest. Forest Ecosystems, 4(1), 1–10.

Querejeta, J. I., Roldán, A., Albaladejo, J., & Castillo, V. ctor. (2001). Soil water availability improved by site preparation in a Pinus halepensis afforestation under semiarid climate. Forest Ecology and Management, 149(1–3), 115–128.

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Rai, P., & Singh, S. (2010). A survey of clustering techniques. International Journal of Computer Applications, 7(12), 1–5.

Ramantswana, M., Brink, M., Little, K., Spinelli, R., & Chirwa, P. (2021) Perspectives and drivers of modernisation of silviculture reestablishmentin South Africa. Southern Forests: a Journal of Forest Science, 83 (1), 79-87.

Ranalli, M., & Rocci, R. (2019). A Comparison Between Methods to Cluster Mixed-Type Data: Gaussian Mixtures Versus Gower Distance. Scientific Meeting of the Classification and Data Analysis Group of the Italian Statistical Society, 163–172.

Ritchie, G. A., & Dunlap, J. R. (1980). Root growth potential: its development and expression in forest tree seedlings. NZJ For. Sci, 10(1), 218–248.

Rivers, M., Beech, E., Bazos, I., Bogunić, F., Buira, A., Caković, D., Carapeto, A., Carta, A., Cornier, B., Fenu, G., & others. (2019). European red list of trees. International Union for Conservation of Nature and Natural Resources (IUCN).

Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. Journal of Computational and Applied Mathematics, 20, 53–65.

Sarantakos, S. (2017). Social research. Bloomsbury Publishing.

Schmidt, M. G., Macdonald, S. E., & Rothwell, R. L. (1996). Impacts of harvesting and mechanical site preparation on soil chemical properties of mixed-wood boreal forest sites in Alberta. Canadian Journal of Soil Science, 76(4), 531–540.

Sikström, U., Hjelm, K., Hanssen, K. H., Saksa, T., & Wallertz, K. (2020). Influence of mechanical site preparation on regeneration success of planted conifers in clearcuts in Fennoscandia-a review.

Smethurst, P. J. (2010). Forest fertilization: trends in knowledge and practice compared to agriculture. Plant and Soil, 335(1–2), 83–100.

Stanton, B., Eaton, J., Johnson, J., Rice, D., Schuette, B., & Moser, B. (2002). Hybrid poplar in the Pacific Northwest: the effects of market-driven management. Journal of Forestry, 100(4), 28–33.

Stanturf, J. A., Van Oosten, C., Netzer, D. A., Coleman, M. D., & Portwood, C. J. (2001). Ecology and silviculture of poplar plantations. Poplar Culture in North America, Part A, 153–206.

Steele, J. K., Aust, W. M., & Seiler, J. R. (2021). Effects of Mechanical Site Preparation, Planting Stock, and Planting Aids on the Survival and Growth of American Sycamore in a Marginal Old Field Riparian Restoration. Forests, 12(10), 1295.

Steudle, E. (2001). The cohesion-tension mechanism and the acquisition of water by plant roots. Annual Review of Plant Biology, 52(1), 847–875.

Tognetti, R., Smith, M., & Panzacchi, P. (2022). Climate-smart forestry in mountain regions. Springer Nature.

Walday, M., & Kroglund, T. (2002). Europe's Biodiversity-biogeographical Regions and Seas. Seas Around Europe: The Baltic Sea-the Largest Brackish Sea in the World. European Environment Agency.

Williams, M. I., & Dumroese, R. K. (2013). Preparing for climate change: forestry and assisted migration. Journal of Forestry, 111(4), 287–297.

Yanchuk, A., Allard, G., & others. (2009). Tree improvement programmes for forest health – can they keep pace with climate changes. Unasylva, 60(231/232), 50–56.

Supplementary Materials

Tabe S1: Statistical assessments of the differences between the regions concerning the importance attributed to early measures for stand establishment in i) the future and ii) the future in contrast to the past. The table contains the results for the the measures as well as the post-hoc verification. For further details refer to the text.

Tabelle S1: Statistische Analyse der Unterschiede zwischen den Regionen betreffend die den Bestandesbegründungsmaßnahmen zugemessene Bedeutung, und zwar i) in Zukunft ii) in Zukunft im Unterschied zur Vergangenheit. Die Tabelle enthält die Ergebnisse zu den aufgelisteten Maßnahmen als auch zu den post-hoc Untersuchungen (paarweise Gegenüberstellung der einzelnen Regionen innerhalb einer jeweiligen Maßnahme). Weitere Details finden sich im Text.

	Urgency in the future	Difference between urgency in the future and the past	
	p-value	*p-value*	*p-value*
		Kruskal Wallis-test	
Measure			
Against drought	0.065	**0.003 ***	
Fertilization nutrients	0.178	0.054	
Fertilization growth	0.054	**0.016 ***	
Against soil compaction	**0.015 ***	0.618	
		Dunn test	
Pairs of regions	Against soil compaction	Against drought	Fertilization growth
Atl – Atl Cont	0.569	0.274	0.440
Atl - **Boreal**	**0.024 ***	0.266	**0.039 ***
Atl Cont - **Boreal**	**0.035 ***	**0.001 ***	**0.048 ***
Atl - Cont	0.481	0.918	0.369
Atl Cont - Cont	0.807	0.101	0.624
Boreal - Cont	**0.034 ***	0.222	0.149
Atl – Atl Med	0.485	0.796	0.605
Atl Cont – Atl Med	0.780	**0.031 ***	0.642
Boreal – Atl Med	**0.038 ***	0.296	**0.020 ***
Cont – Atl Med	0.915	0.883	0.440

*Significance level α < 0.05 **

Tabe S2: Silhouette coefficients as measures for the goodness of clustering.

Tabelle S2: Silhouette Koeffizienten als Maßzahlen für die statistische Genauigkeit der Clusteranalyse.

Goodness of clustering	
Cluster	Silhouette coeff
1	0.15
2	0.27
Model total	0.36

0 - 0.25 no structure 0.26 – 0.5 weak structure 0.51 – 0.75 middle structure 0.76 – 1 strong structure

Questionnaire

Early operations at stand establishment

The questionnaire contains two sections (to be filled):

1. General information on practices at stand establishment applied by your company

2. Description of the measures practiced by your company as to

a) Irrigation/Water supply + example for illustration

b) Mechanical site preparation + example for illustration

c) Fertilization + example for illustration

If you are not able to give information to a particular question, please feel free to skip.

However, we are grateful for any information. Please note, it is not required to give scientifically substantiated answers, it´s essential to communicate your personal experience and opinion!

Thank you!

Company:

Email adress:

Intensity levels ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high					
General information on practices applied by your company					
According to your opinion, what are nowadays the key aspects for successful stand establishment? What matters the most?					
In your company, what is the priority of the here listed measures at present? *From 1 to 5*	*Against drought*	*Fertilization against lack of nutrients*	*Fertilization for enhancing growth*	*Against soil compaction*	*Other measures (if available)*
	Please name other measures (if available)				
In your company, what was the priority of the here listed measures in the last 10 years? *From 1 to 5*	*Against drought*	*Fertilization against lack of nutrients*	*Fertilization for enhancing growth*	*Against soil compaction*	*Other measures (if available)*
In your opinion, what will be the priority of the here listed measures within the next 10 years? *From 1 to 5*	*Against drought*	*Fertilization against lack of nutrients*	*Fertilization for enhancing growth*	*Against soil compaction*	*Other measures (if available)*
During the last 10 years, could you observe an increase of the failure rate at stand establishment? Yes / No If so, to what percentage (see right hand)	< 10	10-30	30-50	50-70	>70
At present, what is the most essential problem at stand establishment (water scarcity, lack of nutrients, soil compaction, or other problem(s)?)					
Has this problem intensified during the last 10 years? ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
If so (see previous question) to what percentage have the costs increased (approx..) – compared to the situation 10 years ago?	< 10	10-30	30-50	50-70	>70

Description of the measures applied by your company

The measures include three aspects: Irrigation/water supply, mechanical site preparation, fertilization.

In the following, in a first section please give a general explanation of the measure you want to describe, and in a second section please describe a concrete example for illustration, respectively.

How to classify a measure, is defined by the purpose. For example, if you practice soil scarification with the purpose of enhancing the water infiltration, please put it in the section *irrigation/water supply*, otherwise in the section *mechanical site preparation*.

Please note: It is not required to give scientifically substantiated answers, it´s essential to communicate your personal experience and opinion!

Irrigation/Water supply

In this context, the term irrigation comprises systems where the water is being transported to the stand, e.g. sprinklers, drip irrigation, irrigation with tanker…

In contrast, we define (alternative sustainable forms of) water supply as given when methods are applied for retaining, storing and re-distributing the available (rain)water on a particular site, e.g. by mulching…

What is the name of the measure?					
Which work steps are included, how do you proceed?					
Under which conditions do you use this method?					
What does one have to pay attention when using this method? What is your personal recommendation?					
What do you expect from this method? If omitting this method, what would probably happen?					
Did this method fulfil your expectation? *From 1 to 5* ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
Has the use of this method intensified during the last 10 years? *From 1 to 5* ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
What are the approx. costs per ha?					
According to your personal opinion, is this method reasonable? Why?					
Other remarks as to this method.					

Concrete example for the above-described method for irrigation / water supply Please designate the stand unambiguously, in case you report this stand also in another category, like mechanical site preparation or fertilization.	
What is the name of the measure illustrated by the following example (and described above)?	
Name of the stand (if available)	
Location (eventually coordinates)	
Sea level	
Slope exposition	
Slope inclination (approx.)	
Geomorphological characteristics (e.g. remarkable soil elevations and depressions…)	
Soil depth (organic layer, mineral soil layer, approx.)	
Included tree species and share of tree species (in tenths, referring to stem number)	
Spacing pattern/distances? Stem number/ha?	
If mixture: tree by tree or in mono-species patches?	
In what year occurred the stand establishment? In what season? What was the age of the trees at planting?	
What was the planting technique?	
What was the age of the plants when the here-described measure was applied?	
Why was the measure performed (reaction to problem, out of routine, preventively?)	
Costs/ha?	
Did the measure fulfil the expectation?	
Were there any further specific details at stand establishment and early operations on this stand?	

Mechanical site preparation					
What is the name of the measure?					
Which work steps are included, how do you proceed?					
Under which conditions do you use this method?					
What does one have to pay attention when using this method? What is your personal recommendation?					
What do you expect from this method? If omitting this method, what would probably happen?					
Did this method fulfil your expectation? *From 1 to 5* ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
Has the use of this method intensified during the last 10 years? *From 1 to 5* ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
What are the approx. costs per ha?					
According to your personal opinion, is this method reasonable? Why?					
Other remarks as to this method.					

Concrete example for the above-described method for mechanical site preparation Please designate the stand unambiguously, in case you report this stand also in another category, like irrigation/water supply or fertilization.	
What is the name of the measure illustrated by the following example (and described above)?	
Name of the stand (if available)	
Location (eventually coordinates)	
Sea level	
Slope exposition	
Slope inclination (approx.)	
Geomorphological characteristics (e.g. remarkable soil elevations and depressions…)	
Soil depth (organic layer, mineral soil layer, approx.)	
Included tree species and share of tree species (in tenths, referring to stem number)	
Spacing pattern/distances? Stem number/ha?	
If mixture: tree by tree or in mono-species patches?	
In what year occurred the stand establishment? In what season? What was the age of the trees at planting?	
What was the planting technique?	
What was the age of the plants when the here-described measure was applied?	
Why was the measure performed (reaction to problem, out of routine, preventively?)	
Costs/ha?	
Did the measure fulfil the expectation?	
Were there any further specific details at stand establishment and early operations on this stand?	

Fertilization					
What is the name of the measure?					
Which work steps are included, how do you proceed?					
Under which conditions do you use this method?					
What does one have to pay attention when using this method? What is your personal recommendation?					
What do you expect from this method? If omitting this method, what would probably happen?					
Did this method fulfil your expectation? *From 1 to 5* ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
Has the use of this method intensified during the last 10 years? *From 1 to 5* ***1*** very low ***2*** low ***3*** medium ***4*** high ***5*** very high	1	2	3	4	5
What are the approx. costs per ha?					
According to your personal opinion, is this method reasonable? Why?					
Other remarks as to this method.					

Concrete example for the above-described method for fertilization Please designate the stand unambiguously, in case you report this stand also in another category, like mechanical site preparation or irrigation/water supply.	
What is the name of the measure illustrated by the following example (and described above)?	
Name of the stand (if available)	
Location (eventually coordinates)	
Sea level	
Slope exposition	
Slope inclination (approx.)	
Geomorphological characteristics (e.g. remarkable soil elevations and depressions…)	
Soil depth (organic layer, mineral soil layer, approx.)	
Included tree species and share of tree species (in tenths, referring to stem number)	
Spacing pattern/distances? Stem number/ha?	
If mixture: tree by tree or in mono-species patches?	
In what year occurred the stand establishment? In what season? What was the age of the trees at planting?	
What was the planting technique?	
What was the age of the plants when the here-described measure was applied?	
Why was the measure performed (reaction to problem, out of routine, preventively?)	
Costs/ha?	
Did the measure fulfil the expectation?	
Were there any further specific details at stand establishment and early operations on this stand?	

Additional:

Please just list measures for irrigation/water supply, mechanical site preparation, fertilization that are being practiced in your company and that have not been mentioned in the previous chapters: