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Biomass production dynamics for common forest tree species in Denmark – Evaluation of a common garden experiment after 50 yrs of measurements

Thomas Nord-Larsen [a,*], Hans Pretzsch [b]

[a] University of Copenhagen, 23 Rolighedsvej, DK-1958 Frederiksberg C, Denmark
[b] Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

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ABSTRACT

Common gardens are suited for analysing the behaviour of different species in a common environment. We used a common garden experiment including 12 different tree species (*Fagus sylvatica*, *Pseudotsuga menziesii*, *Abies grandis*, *Larix kaempferi*, *Chamaecyparis lawsoniana*, *Pinus contorta*, *Pinus mugo*, *Abies procera*, *Picea abies*, *Quercus robur*, *Abies alba*, and *Picea sitchensis*) grown at 13 different sites, and representing almost 50 yrs of measurements, for answering the following questions: (i) how do the species differ in their average biomass production?, (ii) how does their performance vary in space, and (iii) how does their performance vary over time. The analyses showed that the North American conifers including *A. grandis*, and *P. sitchensis* had a significantly higher potential for biomass production than the other species. However, while *P. sitchensis* was relatively invariant to site conditions, the analysis indicated that, compared to the other species, *A. grandis* benefited more than the other species from a general improvement in growing conditions. The effectiveness of substituting fossil fuels and carbon intensive materials with woody bioenergy is highly dependent on plant growth rates. Our results may suggest a selection of species with superior biomass production and carbon sequestration.

1. Introduction

A common garden experiment, also known as a transplant experiment, is an experiment for analysing the behaviour of different species in a common environment. An essential advantage of the common garden design compared with scattered long-term experiments including various species but in disjunct design is that they allow unimpaired comparison of the species at the given sites. Because the organisms develop in the same "garden", their environmental conditions, such as day length, sunlight, rainfall, temperature, and soil are the same. This avoids confounding effects, and allows the comparison of species behaviour under *ceteris paribus* conditions.

Common gardens were first used to analyse the behaviour of herbaceous plants (Tansley, 1917), then also of woody plants (Cheplick, 1992; Kullman, 1993), animals (Pelini et al., 2012), and other organisms (Cheplick, 2008; Wikelski et al., 2003). Common garden experiments may comprise monocultures of different species or provenances of a species, or even mixed cultures of selected species. If several common gardens are established, for instance along an ecological gradient, they may reveal the species-specific performance in dependence on the environmental conditions (Oleksyn et al., 1998). They can contribute to ecosystem understanding (e.g., site-growth relationship, adaptation, intra- and inter-specific competition and facilitation) but also to practical decision making (e.g., species or provenance selection for maximising stand productivity, quality, and resistance). As common garden experiments established across wide ecological gradients, support the selection of species and provenances suited for different climatic regimes, they currently undergo a revival in view of climate change (Reich and Oleksyn, 2008).

Although forest science and practice are commonly focused on the long term development of tree species under various site conditions, we found just a very few studies reporting about the growth and productivity from common garden experiments. Analysing *Nothofagus pumilio* in common gardens, Premoli et al. (2007) found a strong effect of altitude on morphology and phenology. A similar effect of altitude on cold resistance of *Picea abies* was observed by Oleksyn et al. (1998). Based on common garden studies, Reich and Oleksyn (2008) and Kullman (1993) found strong relationships between climate and growth and survival for *Pinus*

* Corresponding author.
E-mail address: tnl@ign.ku.dk (T. Nord-Larsen).

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sylvestris and *Betula pubescens*, respectively. Although the initial intention of common gardens was the comparison of a broader set of species regarding their productivity on different sites, we did not find such evaluations except common gardens with various provenances of a given species (Aitken et al., 2008; Voltas et al., 2008).

In Denmark, a common garden trial was established in 1965 including 12 exotic and indigenous tree species at 13 locations along an productivity gradient. Today, depending on tree species and site quality, many of the stands have reached maturity and have been measured up to eight times. In view of the rather poor knowledge base of long term growth extracted so far from common gardens, our experiment appears rather unique. We use it for answering the following questions: (i) how do the species differ in their average biomass production?, (ii) how does their performance vary in space, i.e., along the productivity gradient? and (iii) how does their performance vary over time, i.e., in different survey periods? We used biomass production rather than volume growth and yield, to better capture species specific differences in biological productivity.

2. Materials and methods

The common garden experiment was established to investigate and compare the growth and health of the 12 tree species included: *Fagus sylvatica* L., *Pseudotsuga menziesii* (Mirb.) Franco, *Abies grandis* (Douglas ex D. Don) Lindley, *Larix kaempferi* (Lamb.) Carr., *Chamaecyparis lawsoniana* (A. Murray) Parl., *Pinus contorta* Douglas, *Pinus mugo* Turra var. Rostrata, *Abies procera* Rehder, *Picea abies* (L.) Karst., *Quercus robur* L., *Abies alba* Mill., and *Picea sitchensis* (Bong.) Carr. The tree species were chosen among those commonly grown or predicted to be of future importance in Danish forestry at the time.

The experiment is located on 13 sites in Denmark (Fig. 1). The sites were selected to include most typical Danish site types ranging from the sandy outwash planes and harsh Atlantic climate in the western part of the country, the gravelly tills and intermediate climate in the central parts and the clayey soils and more continental climate in the eastern parts. The former land uses of the selected sites included cropland, heathland, forest and oak scrub, with the larger part being former cropland (Table 1). The diversity of former land uses was accepted to be able to obtain homogeneous sites, each of a total size of about 3 ha.

The trials were established in the autumn 1964 and the spring 1965. At each site, 12 essentially square or rectangular plots of about 0.25 ha, one for each species (Table 2), were laid out before planting. Generally, the individual tree species were distributed randomly among the plots. For each species, the same provenance was planted across all sites. Provenances used were standard provenances according to Gøhrn (1957) and were mostly Danish land races, phenotypically selected as suitable for wood production in Denmark (Table 2). However, in some cases, the seed sources were of native foreign origin that had previously been shown to

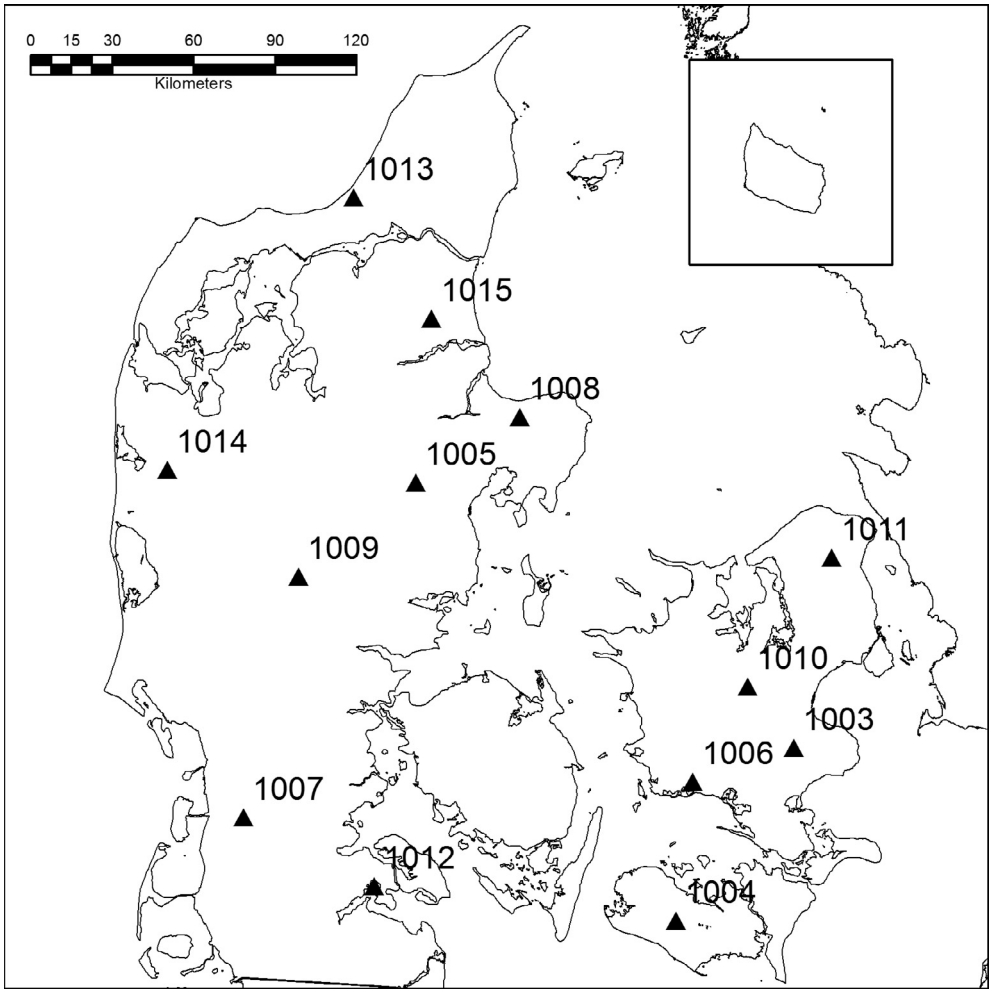

Fig. 1. Location of the field trials included in the common garden experiment. Each site included 10 conifer and 2 broadleaved species.