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## **Vulnerability of Douglas-fir in a changing climate: study of decline in France after the extreme 2003's drought**

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With 385.000 ha, Douglas-fir is an important species in France, especially in private forests. It is the first exotic tree species planted in France. Some of the most important productive regions in France have suffered an important decline and dieback after the 2003 drought and heat wave. This decline caused early mortality and loss of production. The main aim of this study was to answer foresters' questions concerning the causes of decline. The authors analysed Douglas-fir decline and dieback in France using two joint approaches. First a national study was performed using the Forest Health Department (DSF) database. Second a regional dendroecological study included soil and site description, dendrometric and biotic observations as well as soil water balance calculation in all sampled stands.

### **Spatial and temporal Douglas-fir decline analysis at the national scale**

The Forest Health Department database reported all mentions of biotic and abiotic problems on Douglas-fir between 1989 and 2006 (as described by permanent forest health survey agents). Comparison between mentions of decline and other types of observation allowed to map and reconstruct the chronology of Douglas-fir decline in France and to identify vulnerability factors at the national scale. Douglas-fir decline was mapped using reference events and decline events with quadratic kernel estimator (grid 10km x 10km, window 90km).

This map shows three main declining regions: two production regions (Burgundy and Midi-Pyrénées) and one region where Douglas-fir is less current - north-west of France (Normandy, Pays de la Loire). Not all production regions are affected. This map raises one question: when did this decline occur? To answer this question the rate of annual decline mentions was calculated for each three "DSF regions" concerned by declines between 1989 and 2006. Declines took place during different periods. In North-West DSF region mentions of decline occurred during three periods (1990-1991, 1999, 2003-2005). In the two other regions the declines are more recent (2001, 2003-2006 in south-west France and 2002-2006 in Massif Central). The 2003 drought affected especially those regions. Preliminary results show significantly higher soil water deficit (cumulated on three years) as computed by soil water balance modelling for periods with declines. Soil water deficit seems to be a determinant factor in recent declines in these two regions. In north-west France declines are older. Inappropriate station condition could explain old and recurrent declines. To complete this result, factors of vulnerability were identified using a logistical regression. A model was developed, including topography, mean annual temperature, total annual rainfall and growing-season rainfall. Thresholds of decline were identified using a regression tree. The main explicative trends which were able to be extracted from these results were drawn at the national scale. Main trends can locally vary with local off-set factors. These local factors (soil water capacity, silviculture, leaf area index) were not available. Their contribution was analysed in the second part of this study.

**Douglas-fir decline analysis at regional scale**

A retrospective analysis of radial growth, microdensitometric profiles and daily soil water balance calculation was performed. The purposes were to date growth reduction, to quantify the impact of drought events on radial growth and tree ring properties, to search past growth pattern related to actual tree health or tree mortality. Site conditions, silviculture and biotic interactions were tested as vulnerability sources. We selected two regions severely impacted in 2003 according to the Forest Health Department database. These regions were the second (Burgundy) and the fourth (Midi-Pyrénées) among Douglas-fir production regions. 30 plots were selected in each region, 1768 trees were observed and 925 healthy or declining trees were cored to the pith. Tree ring width and microdensity profiles were measured and related to climatic data and drought indices. Growth reduction was related to local soil water deficit. Pointer years were related to both management (thinning) and soil water deficit indices. The 2003 drought was the most severe according to soil water deficit calculation in Burgundy, while recurrent drought years during the last decade were pointed out in Midi Pyrénées region. The impact of either extreme drought or recurrent droughts on Douglas fir growth and health will be compared. Main factors of vulnerability and threshold of irreversible dieback will be presented and discussed.