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The Decline of *Pinus sylvestris* L. Forests in the Swiss Rhone Valley - a Result of Drought Stress?

By

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S u m m a r y

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In Scots pine forests in the inner valleys of the European Alps high mortality of unknown causes has recently been observed. In 2002-2003 we assessed forests in the Swiss Rhone valley on a systematic grid ranging in altitude between 440 m and 1550 m a.s.l. We tested if mortality rates since the National Forest Inventory (NFI) in 1983/85 differed between species, geographic regions, altitudinal ranges or potential drought stress (extrapolated difference between annual precipitation (P) and modeled potential evapotranspiration (PET) for the period 1961-90). We also correlated annual pine mortality for a local long-term forest research site (LWF) with climatic data.

At the LWF site 59% of the pines died between 1996 and 2004. Annual mortality rates varied substantially between years and were highest following the drought years 1998 and 2003. Mortality related best to P-PET of the prior summer (May – August). Pine mortality on NFI plots was higher than elsewhere in Switzerland, while mortality of other species was not. Below 1100 m a.s.l. mortality rates of pines, but not of other species, were higher than above. We found a significant negative relationship between mortality rates and P-PET in pines, but not in the other species. Therefore, we postulate that drought stress triggers the observed pine decline.

I n t r o d u c t i o n

Scots pine (*Pinus sylvestris* L.) forests occur naturally in the inner valleys of the European Alps near the southern limit of the species range. Extraordinarily high tree mortality of Scots pine has recently been observed in several of these in-

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ner-alpine valleys (CECH & PERNY 1998, RIGLING & CHERUBINI 1999). In the Swiss Rhone valley (Valais) these pine forests constitute 11% of the total forest area and reach from the valley floor (400 m a.s.l.) to the sub-alpine forests (2000 m). Here, locally up to 50% of the pines have died since 1995. The exact causes of the present mortality are currently under investigation (BIGLER & al. in press). REBETEZ & DOBBERTIN 2004 showed for the Valais that the number of days with mean temperature above 20°C has doubled over the last 20 years, making trees more susceptible to insects, nematodes or pathogens.

We tested first, if annual mortality rates at a long-term research site (LWF) affected by pine decline correlated with indicators of drought stress, and second, if mortality rates on 201 forest inventory (NFI) plots on a 1x1 km grid in Valais differed by species, geographic regions, altitude or indicators of drought stress.

Material and Methods

At the LWF site Visp, located in the most severe pine decline area at 700 m a.s.l., annual tree mortality for trees with a minimum breast height diameter (dbh) of 12 cm has been recorded since 1996 on a 0.5-ha plot (80 pines) and since 1998 on the whole 2-ha plot (411 pines). From the Swiss NFI data in Valais 1983–1985 (WSL 2002) we selected all 500 m^2 plots with pines up to 1600 m. We recorded whether trees were living, dead or had been harvested since the last inventory. The studied region was divided along the west-east axis into three sections of 30 km length and two altitudinal classes (≤ 1100m, > 1100m). Plots with at least 5 trees (pines versus all other species) were grouped into 3 mortality classes (1: no mortality, 2: up to 20% and 3: >20% mortality).

A drought index was calculated as the difference between precipitation (P) and potential evapotranspiration (PET). PET was estimated using the method by Thornthwaite (BIGLER & al in press.), which requires monthly mean temperatures and latitude. Climatic data obtained from the climate stations of MeteoSwiss for the period 1961-90 were interpolated for the inventory plots using an inverse weighted distance approach (ZIMMERMANN & KIENAST 1999). For the LWF site the time period between the tree assessments ($August_{year\ t-1}$ – $July_{year\ t}$) and for the previous summer period ($May\text{-}August_{year\ t-1}$) was chosen using data from the near-by MeteoSwiss station Visp.

Mortality and removal rates, weighted by stem basal area, were separately computed for pine and all other species in each NFI plot for the interval between the inventories in 1983-1985 and 2002-2003. 95%-confidence intervals were obtained applying statistics for cluster sampling. Kruskal-Wallis tests were applied to compare first mortality percentages between geographic regions and second climatic variables between mortality classes.

Results and Discussion

On the LWF site Visp, 59% of the trees have died between 1996 and 2004. Mortality was highest following the dry summers of 1998 and 2003 (18% and 26% respectively) and least following the wet summer 2002 (0.3%). Mortality rates correlated better with climatic variables of the previous summer (Table 1, correlation coefficients: 0.64 - 0.84) than of the 12-month period (0.23 - 0.54). The drought index of the previous summer had highest or close to highest correlations with mortality rates for both subplot and total plot data. In contrast to related studies (CECH & PERNY 1998, RIGLING & CHERUBINI 1999) these results confirm the hypothesis that drought stress triggers the observed mortality in the Valais (BIGLER & al. in press.). Drought increases the susceptibility of trees to secondary insects and pathogens, while warm summer temperatures increase the reproductive rate of bark beetles (WERMELINGER & SEIFERT 1999) and nematodes.

Table 1. Pearson correlation of annual pine mortality with temperature (T), precipitation (P), potential evapotranspiration (PET) and P-PET of the previous 12 months or the previous summer.

Annual mortality	Period: August$_{year\ t-1}$ – July$_{year\ t}$				Period: May – August$_{year\ t-1}$			
	T	P	PET	P-PET	T	P	PET	P-PET
0.5 ha subplot	0.44	-0.39	0.53	-0.47	0.64	-0.80	0.64	-0.83
2.0 ha full plot*	0.23	-0.28	0.55	-0.37	0.84	-0.67	0.84	-0.80

* values for the years 1996-1998 were taken from the 0.5-ha plot.

On the NFI plots mortality since 1983 for Scots pine up to 1100 m a.s.l. was significantly higher (up to 2 times) than the mortality rates extrapolated from annual rates of 0.4 - 0.5% observed in managed forests in Switzerland (Fig. 1).

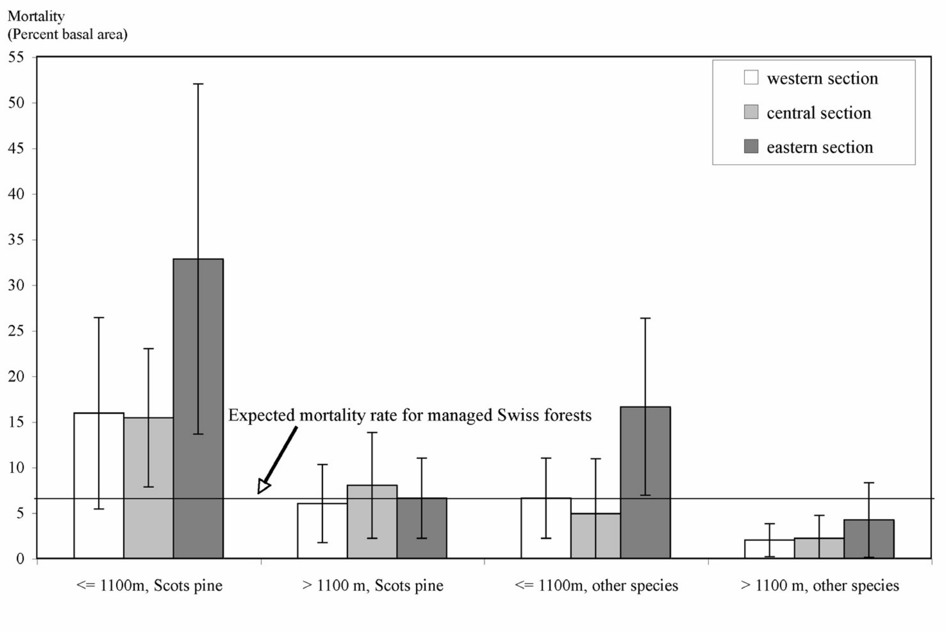

Fig. 1. Mortality percent between 1983-1985 and 2002-2003 for Scots pine and other species by section (west, center, east), and altitudinal classes with 95%-confidence intervals.

Within each section Scots pine mortality was higher than for the other species. Scots pine mortality rates were significantly lower above 1100 m (Kruskall-Wallis statistics: $p = 0.007$), in particular in the eastern section ($p = 0.036$). Only significant differences were also found between altitudinal classes for the other species ($p = 0.029$). We redid the analysis for the combined mortality and removal rates and found a similar relation with geographic location (results not shown). With the exception for Scots pine in the eastern section combined removal rates were not higher than elsewhere in Switzerland, indicating that tree removal did not bias mortality rates.

For non-pine species we found no significant difference in P, PET and P-PET between mortality classes, but for pines all p-values were below 0.1 and for P-PET below 0.05 with lowest mean P-PET in the highest mortality class (Table 2).

Table 2. Mean annual precipitation (P), potential evapotranspiration (PET) and P-PET for plots with at least 5 pines or 5 non-pine trees by mortality classes and Kruskal-Wallis test statistics.

	Scots pine plots				Plots of other species			
Mortality class	n	P (mm)	PET (mm)	P-PET (mm)	n	P (mm)	PET (mm)	P-PET (mm)
No mortality	25	979	450	529	50	1095	450	644
≤ 20% mortality	28	948	464	485	22	1040	465	574
> 20% mortality	16	820	501	319	10	937	496	442
Kruskal-Wallis		p = 0.067	p = 0.052	p = 0.048		p = 0.202	p = 0.231	p = 0.146

Comparing three pine species in north-eastern Spain MARTÍNEZ-VILALTA & PIÑOL 2002 found for Scots pines higher mortality after drought possibly as a result of a higher risk to xylem embolism. The fact that mortality in our study was not restricted to dry sites is evidence that additional stress factors such as insects, pathogens, and mistletoe also play an important role. Insect outbreaks often follow droughts, which decrease the resistance of trees and provide favorable conditions for the reproduction of insects. Therefore, we postulate that drought stress incites the observed pine decline. If temperature increases further, pure pine forests at low altitude will in the long run be replaced by mixed forests.

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