

Phenological monitoring along an altitudinal gradient in the Berchtesgaden National Park, Germany

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Tab. 2 Altitudinal gradient analysis of phenological mean dates based on 10+ year means. Gradients have been calculated as coefficients of linear regression ($\pm$ SE). Bold numbers indicate $p < 0.05$. LU: Beginning of leaf unfolding, LE: Leaves fully expanded, BF: Beginning of flowering, FF: Full flowering, EF: End of flowering, Alt. diff.: Altitudinal difference.

Species	Phenophase	N	R ²	ρ	Days/100m	Altitudinal range [m]	Alt. diff. [m]
<i>Acer pseudoplatanus</i>	LU	9	0.738	0.003	1.6 (± 0.4)	680-1390	710
	LE	10	0.923	<0.001	2.4 (± 0.2)	680-1390	710
<i>Alnus incana</i>	LU	8	0.644	0.017	1.9 (± 0.6)	680-1360	680
	LE	7	0.933	<0.001	2.0 (± 0.2)	680-1280	600
<i>Aposotis foetida</i>	LU	8	0.680	0.012	3.3 (± 0.9)	680-1360	680
	LE	10	0.771	0.001	3.1 (± 0.6)	680-1360	680
	BF	9	0.471	0.041	2.5 (± 1.0)	680-1360	680
	FF	10	0.487	0.025	2.5 (± 0.9)	680-1360	680
	EF	9	0.584	0.017	2.0 (± 0.6)	680-1360	680
<i>Daphne mezereum</i>	LU	6	0.615	0.065	2.8 (± 1.1)	680-1070	390
	LE	7	0.823	0.005	3.2 (± 0.7)	680-1150	470
	BF	5	0.516	0.171	3.2 (± 1.8)	680-1000	320
	FF	6	0.429	0.158	1.8 (± 1.0)	680-1070	390
	EF	6	0.455	0.142	3.9 (± 2.1)	680-1150	470
<i>Fragaria vesca</i>	LU	11	0.549	0.009	1.9 (± 0.6)	680-1360	680
	LE	11	0.688	0.002	3.0 (± 0.7)	680-1360	680
	BF	8	0.003	0.906	0.2 (± 1.3)	685-1070	385
	FF	7	0.016	0.788	0.5 (± 1.6)	685-1070	385
	EF	7	0.580	0.047	2.7 (± 1.0)	685-1070	385
<i>Fraxinus excelsior</i>	LU	4	0.866	0.069	3.0 (± 0.8)	680-960	280
	LE	5	0.883	0.037	2.1 (± 0.4)	680-960	280
<i>Larix decidua</i>	LU	8	0.959	<0.001	3.3 (± 0.3)	695-1280	585
	LE	8	0.948	<0.001	3.0 (± 0.3)	695-1280	585
<i>Mercurialis perennis</i>	LU	11	0.837	<0.001	4.2 (± 0.6)	680-1280	600
	LE	13	0.680	0.001	3.6 (± 0.7)	680-1360	680
	BF	10	0.895	<0.001	5.3 (± 0.6)	680-1215	535
	FF	12	0.725	<0.001	3.2 (± 0.6)	680-1360	680
	EF	12	0.765	<0.001	3.3 (± 0.6)	680-1360	680
<i>Oxalis acetosella</i>	LU	6	0.446	0.147	2.7 (± 1.5)	680-960	280
	LE	5	0.746	0.145	4.5 (± 1.5)	680-960	280
	BF	5	0.550	0.151	2.6 (± 1.4)	680-960	280
	FF	5	0.415	0.241	3.4 (± 2.3)	680-960	280
	EF	5	0.701	0.077	4.6 (± 1.7)	680-960	280
<i>Paris quadrifolia</i>	LU	4	0.130	0.640	0.7 (± 1.2)	680-1060	380
	LE	7	0.863	0.002	4.2 (± 0.8)	680-1215	535
	BF	5	0.957	0.004	2.3 (± 0.3)	680-1060	380
	FF	6	0.840	0.029	2.3 (± 0.6)	680-1060	380
	EF	6	0.840	0.029	3.1 (± 0.8)	680-1060	380
<i>Petasites albus</i>	LE	4	0.843	0.060	2.4 (± 0.6)	695-1280	585
	EF	4	0.682	0.174	2.5 (± 1.2)	695-1280	585
<i>Picea abies</i>	LU	8	0.874	0.001	3.9 (± 0.6)	680-1380	700
	LE	7	0.827	0.005	3.8 (± 0.8)	680-1150	470
<i>Primula elatior</i>	LU	5	0.812	0.037	2.6 (± 0.7)	680-1070	390
	LE	7	0.808	0.006	3.3 (± 0.7)	680-1000	320
	BF	7	0.751	0.012	4.9 (± 1.2)	680-1000	320
	FF	8	0.888	<0.001	4.2 (± 0.6)	680-1070	390
	EF	8	0.730	0.007	3.4 (± 0.8)	680-1070	390
<i>Sorbus aucuparia</i>	LU	5	0.853	0.025	2.5 (± 0.6)	950-1390	440
	LE	6	0.937	0.002	2.7 (± 0.4)	950-1390	440
	BF	5	0.998	<0.001	3.2 (± 0.1)	950-1390	440
	FF	5	0.921	0.010	2.7 (± 0.5)	950-1390	440
	EF	5	0.950	0.005	1.9 (± 0.3)	950-1390	440
<i>Tussilago farfara</i>	LU	6	0.002	0.934	0.4 (± 4.3)	685-1215	530
	FF	6	0.908	0.003	3.6 (± 0.6)	685-1215	530
	EF	5	0.888	0.016	4.5 (± 0.9)	685-1215	530
<i>Valeriana tripteris</i>	LU	4	0.114	0.663	3.1 (± 6.2)	960-1215	255
	LE	6	0.502	0.115	2.6 (± 1.3)	820-1360	540
	BF	4	0.205	0.547	2.5 (± 3.4)	820-1215	395
	FF	6	0.087	0.618	1.4 (± 2.2)	820-1360	540
	EF	6	0.238	0.326	1.7 (± 1.5)	820-1360	540

Discussion

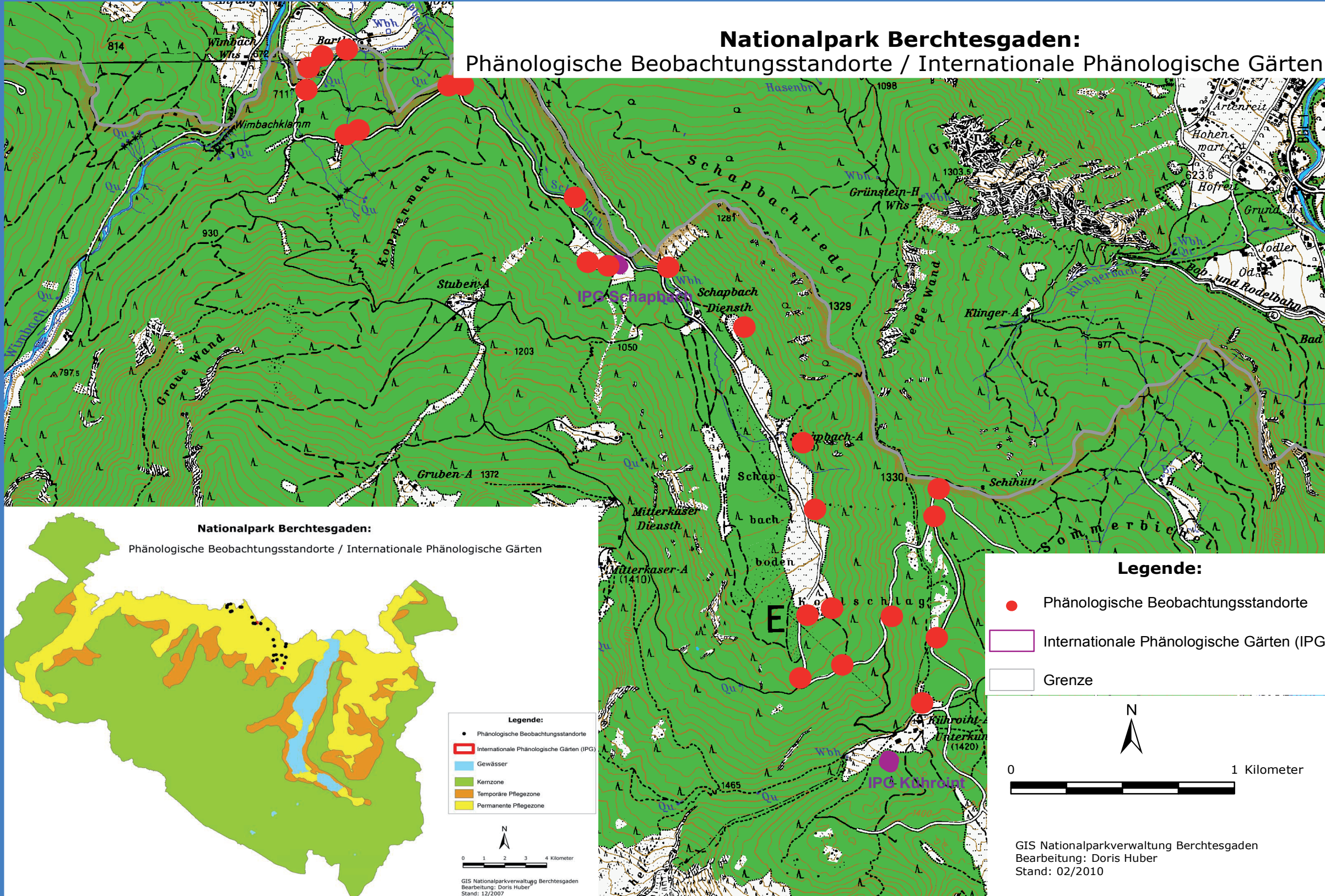
This study allowed to characterize the dependence of phenology on temperature of different species along an altitudinal gradient and to determine the sensitivity of different phenophases to temperature change. However, a significant dependence could not always be shown. All phenophases with a sample size of four sites, for example, are not significant dependent on altitude. Thus, further observations need to be conducted to test whether these results would differ with a bigger sample size.

This poster shows first results. Further analyses are going to be carried out to study the influence of different plant specific traits, such as pollination mode, woodiness and life form on possible effects of recent anthropogenic climate warming.

Results

A significant dependence of phenological mean dates on altitude could be found for 13 out of 16 species (Table 2). No significant dependence on altitude could be found for *Oxalis acetosella* L., *Petasites albus* (L.) Gaertner and *Valeriana tripteris* L.. Only single phenophases are significant dependent on altitude for *Daphne mezereum* L., *Fragaria vesca* L., *Fraxinus excelsior* L., *Paris quadrifolia* L. and *Tussilago farfara* L.. In total a delay in onset dates of 1.6 to 5.3 days per 100 m altitude depending on species and phenophases was determined. The temperature sensitivity for phenophases such as "Beginning of flowering" and "Full flowering" is similar for all species (except for *Mercurialis perennis* L.) whereas phenophase "End of flowering" reveals distinct differences. Both phenophases "Beginning of leaf unfolding" and "Leaves fully expanded" show similar sensitivity to temperature change except for *Fragaria vesca* L..

Fig.1 Observation sites (red dots) along a forest road in the Berchtesgaden National Park (small picture within) including two International Phenological Gardens (IPG; lilac dots).



Methods

Phenological observations

Since 1995 the Berchtesgaden National Park has been running phenological observations on 24 sites along an altitudinal gradient from about 600 to 1400 m (Fig. 1). Every year a total number of thirty species have been observed. Observations have been conducted after the key of Ellenberg (1974; Table 1) once or twice a week from March to July.

Analysis

In this study our attention was focused on five important phenophases: Beginning of leaf unfolding (LU), Leaves fully expanded (LE), Beginning of flowering (BF), Full flowering (FF) and End of flowering (EF; Table 1). To calculate the phenological mean dates, missing data in development were first gap-filled by linear interpolation if possible. Furthermore, only species and phenophases were then taken into account where time series of observations for ≥ 10 years at ≥ 4 sites were given. Thus, 16 out of 30 species could be included in the analyses. The dependence of phenological mean dates on altitude for the five phenophases was calculated as a linear regression.

Introduction

Altitude drives phytophenological phases mainly by means of a temperature decrease of about 0.6°C every 100 m (Barry 1981). Several studies were conducted to investigate the influence of altitude on the phenological development of plants (e.g. Vitasse et al. 2009; Ziello et al. 2009). However, these studies are mostly either based on data observed over a wide area (Dittmar and Elling 2006; Ziello et al. 2009) or over a short period (e.g. Vitasse et al. 2009). The presented dataset consists of phenological observations along an altitudinal gradient of about 800 m performed along a single forest road over 12 years. Furthermore, in comparison to other studies the entire leaf and flower development of trees, shrubs and herbs were observed. Our objective was to test whether there is a dependence of altitude on phenophases of all species and how the sensitivity of phenophases to temperature differs.

Tab.1 Description of the phenological growth stages for leaf and flower development after Ellenberg (1974). Blue coloured stages indicate those focused on in the analyses.

Leaf development		Flower development
Winter dormancy: leaf buds closed	0	Winter dormancy: inflorescence buds closed
Beginning of leaf bud swelling	1	Beginning of inflorescence bud swelling
Leaf buds swollen	2	Individual flower buds swollen
End of leaf bud swelling: Buds just before bud breaking	3	End of flower bud swelling: buds just before bud breaking
Beginning of leaf unfolding	4	Beginning of flowering
Leaves reach 25% of final size	5	Up to 25% of flowers open
Leaves reach 50% of final size	6	Up to 50% of flowers open
Leaves reach 75% of final size	7	Full flowering
Leaves almost fully expanded	8	Flowers fading
Leaves fully expanded	9	End of flowering

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Acknowledgement The study was pursued within the framework of the joint research center FORKAST and was funded by the "Bavarian Climate Programme 2020"