

Ecological altitudinal zoning and its climatic explanation (an example of the Slovene Alps)

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SUMMARY

The upper lines of the forest, of permanent agrarian settlement and of maize cultivation for grain in the Slovene mountains is discussed. The variations in these upper limits are interpreted with reference to various climatic elements. The fact that they diminish in altitude towards the south-west coincides with figures for diminishing precipitation during the year and in the growing season. Phenological rhythm is retarded at altitudes above the thermal belt by one day per 300 m of altitude. This is further illustrated by the fact that a more oceanic climate, with a displaced temperature curve pertains to these altitudes, in comparison to the lowlands. The influence of windiness on phenological phases in the basins and mountain areas is stressed.

The south-eastern border of the Alps in Slovenia (NW Yugoslavia) consists of high, alpine mountains, (the Julian Alps, up to 2863 m, Kamnik-Savinja Alps and the Karawanken) and of the so-called Prealpine mountains. These flank the high alpine mountains from the Friuli lowland in Italy to the lowland of Graz in Austria, and their peaks vary between about 1200 and 1600 m. Annual precipitation varies in different regions from between 1200 to 3000 mm, increasing towards the S and SW and reaching 4000 mm in some places on the southern rim of the Julian Alps. The western Prealpine system appertains to the Sub-Mediterranean climatic system. In the rest of the Slovene Alps, the climate can be classified as Central-European or Alpine, and in the NE and E of Slovenia, as Sub-Pannonian.

The high alpine mountains are too low for determining the snow line. They provide better conditions for determining the forest line.

1. FOREST LINE

Figure 1 shows the altitudes of the forest line in the E and SE Alps. It was prepared by Marek (1905) and was - as regards the Slovene Alps - improved by Melik (1954). After him, the forest line was studied in greater detail by Plesnik (1971), Lovrenčak (1977) and Gams (1977). According to all these studies, the lowest forest line is in SW and S Slovenia on the border mountains where the transition from Sub-Mediterranean climate to the con-

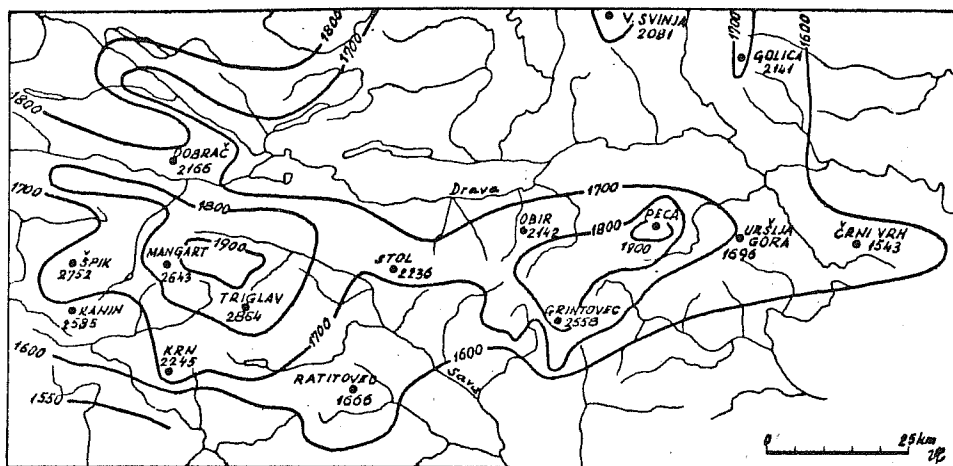


FIG. 1 - Forest line in Slovenia.

tinental climate of Slovenia occurs. It is there that the lowest forest line can be found on the Dinaric mountain, Mali Goljaki (1495 m), but it has some of the characteristics of the secondary (anthropogenic) forest line (Plesnik, 1971, Wraber, 1970), although there is a normal decrease in tree height with altitude, and a vegetational spreading (as is significant for a climatic forest line-Plesnik, 1971a). The proper climatic forest line composed of beech can be found on Mt Notranjski Snežnik (1796 m) and Matajur (1641 m), in both cases at an altitude of 1550-1570 m (Lovrenčak, 1977).

In Melik's opinion, the notion of the forest line is identical with that of the tree line. Therefore he has determined it on the bases of the highest occurrence of more or less dense tree groups on the mountain slopes. The forest line, as determined by him, can be regarded as the present optimal ecological tree line. There has clearly been a continuous rising of the tree line until recently, as documented by Marek (1905) and Melik (1954) (for example, on Mt Uršlja gora from 1600 to 1680 m), as a consequence of the abandoning of pastures and probably also of the higher temperatures this century.

The forest line is getting higher to the north. What is remarkable is that the highest forest line is not in the central high alpine mountains between the Triglav group and the W Karawanken, but at the eastern end of the high Karawanken. There, on the southern slope of Mt. Peca (2126 m), the tree line is at 1900-1950 (Gams, 1976). Mt. Peca is the easternmost Karawanken peak exceeding 2000 m and is on the corner of the high alpine mountains.

Three meteorological stations provide evidence in the search for climatic explanation for the 300 m variation in the altitude of the forest line in Slovenia: Komma in the SW, Krvavec in the Kamnik Alps and Ribniška koča in NE Slovenia. The mean July temperatures for the period 1931-1960 are:

Komma, 1520 m, 12.7°, Krvavec, 1700 m, 11.4° and Ribniška koča, 1510 m, 13.9° (Furlan, 1965, Pučnik, 1980). The orographic forest line is in the vicinity of the Komna station (the climatic line seems to be a little higher). On Mt Pohorje it is presumably at the altitude of 1600-1650 m. The stations Krvavec and Mt. Uršlja gora are closer to the forest line where, at around 1700 m, the July temperature is 10.5° (Gams, 1982). The station at the lowest forest line shows the highest July temperature (Komma). But we have to take into account the different positions of the meteorological stations: Komma is on the border of the karst plateau, Ribniška koča on a northern slope of the alpine mountain and Uršlja gora is situated on a mountain top. The Krvavec and Uršlja gora stations recorded a temperature of 10° or above (Lovrenčak, 1983) for the same number of days (68).

The daily minimum temperatures shown in the following table present a stranger picture:

TABLE I - Daily minimum and daily maximum temperatures on the forest line.

Station mountain altitude	Period	Daily temperatures in °C					
		1.IV - 30.IX		1.VI - 31.VIII		July	
		min.	max.	min.	max.	min.	max.
Komma Julian Alps, 1520 m	1956-80	5.8	14.3	7.0	15.5	7.8	16.5
Ribniška koča Pohorje 1510 m	1926-70	5.9	14.1	7.2	15.8	7.6	16.7
Uršlja gora E Karawanken 1700 m	1966-80	5.8	13.0	6.9	14.6	7.7	15.3

The daily maximal temperatures in July at the cited stations are 3°C higher than the midday temperatures on the forest line in the rest of Alps (Mikula and Quervain, taken from Hermes, 1955, 256).

Even if the different position and altitudes of the stations are taken into account, we cannot explain the 300 m difference in altitude of the forest line between the W and the E Slovenian Alps by the temperature differences in the growing season alone.

The role played by the amount of precipitation during this season, which is shown in the table II, is more obvious.

A similar amount of precipitation to that shown for Komna occurs in the S and SW border of the Julian Alps and the Dinaric mountains, where the lowest forest line in Slovenia is found. So the amount of precipitation is of greater importance in determining the different altitudes of the forest line.

2. ALTITUDE OF PERMANENT AGRARIAN SETTLEMENT

According to the research carried out on Mt Pohorje (a part of the Central Alps in Slovenia), the altitude of isolated farms closely coincides with the

TABLE II - Precipitation.

Station altitude, m	Period	Precipitation in mm		
		1.IV - 30.IX	1.VI - 31.VIII	July
Komna 1520	1931-60	1340	789	247
Obir 2044	1919-1930	856	538	162
Ribniška koča 1510	1931-60	727	427	160

Note: Mt Obir is near to Mt Peca, which has the highest forest line in Slovenia.

upper limit of wheat and rye cultivation as practised in past centuries (Gams, 1959). In areas where hamlets and villages are the main form of settlement, their uppermost line is lower, although the reason for this has not yet been established.

The uppermost line of permanent agrarian settlement in Slovenia was determined by recording the altitude of the highest settlements where slopes rise still higher. Reproduced here is the map drawn by Gams (1960, fig. 2). The line is at its lowest in southern Slovenia, in the region of Pivka: about

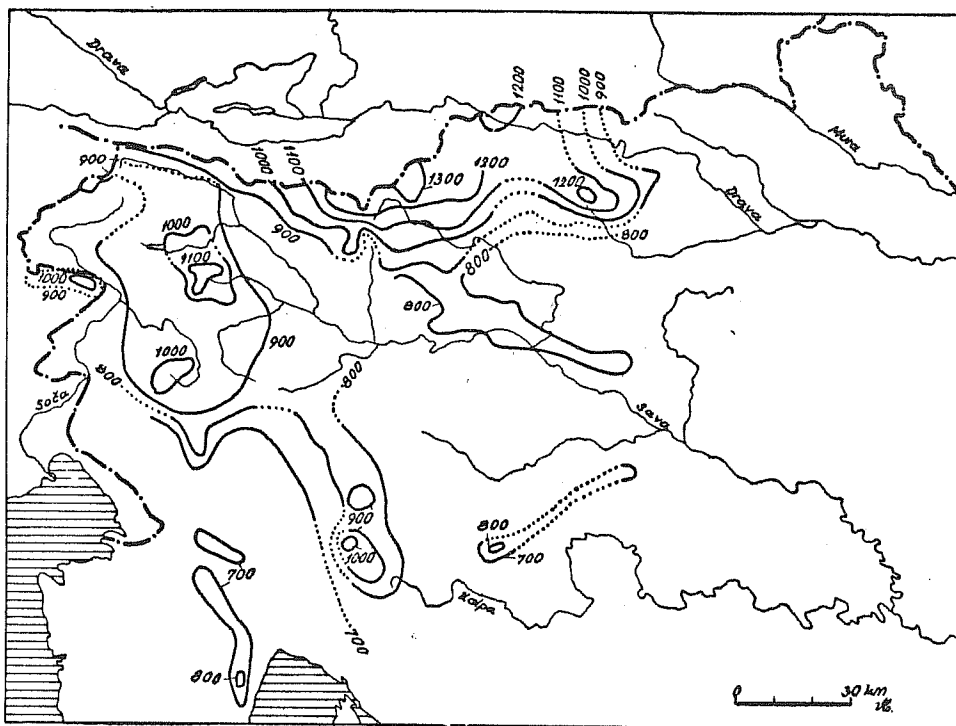


FIG. 2 - Upper limit of the permanent agrarian settlement in Slovenia.

700 m, but it is here presumably more subject to orographic considerations. In the SW Slovenia, the line occurs at between 800 and 900 m, and rises toward the N and NE. Its highest level is between Mts Raduha, Olševa and Peca in E Karawanken, where the highest forest line has also been recorded above. There the highest isolated farms lie at an altitude of 1330 - 1340 m.

Generally speaking, the forest line and the upper line of agrarian settlement show similarity in that they are lowest in S and SW Slovenia and highest in the NE Slovenian Alps.

Evidence of the climatic reasons for the various heights of settlements comes from three meteorological stations: Gomance on the Mt Notranjski Snežnik (1796 m), for the region with the lowest settlement line; Planina under Mt Golica, in the western part of the Karawanken, and Sv. Jošt for the eastern part of the Karawanken.

TABLE III - Temperatures in the altitude of 937-1058 m.

Station altitude	Period	Daily temperatures in °C					
		1.IV - 30.IX		1.VI - 31.VIII		July	
		min.	max.	min.	max.	min.	max.
Gomance 937 m	1919-1938	7.7	18.8	8.8	20.3	9.4	21.4
Planina pod Golico, 1058 m	1919-1938	8.6	18.0	9.9	19.7	10.6	20.8
Sv. Jošt 1064 m	1919-1938	8.6	17.5	10.1	19.5	11.0	20.5

Notes: the Gomance station is situated in a shallow blind valley on the S slope of Mt. N. Snežnik. The daily minimum temperatures are therefore lower than at the stations in N Slovenia. The Planina station is on a southern slope, and the Sv. Jošt station on the top of a ridge where the frequent wind causes the lower daily maximal temperatures and lower line (Gams, 1977).

The only safe conclusions that can be drawn from this comparison is that the local exposition on the slope at an altitude of 900-1100 m, is more important than the actual altitude of the stations. No essential differences between the S and the N of Slovenia as regards temperatures can be found to explain the varying altitudes of the upper line of settlement.

The low snow and forest line on the border mountains of the large mountain systems is usually explained in the literature by the greater cloudiness and higher precipitation that occurs in the central mountain areas (Hermes, 1955). The data at our disposal do not permit a re-examination of this rule as it applies to the Slovene Alps as regards the degree of cloudiness. As the effect of cloudy weather is most apparent in the form of reduced radiation, the radiation energy in our region can be established by data from three stations situated at an altitude between 880 and 1070 m.

According to the table IV, there are no major differences in radiation

TABLE IV - Total energy of global radiation in kWh/m² (1960-79) (Hočvar et al., 1982).

Station, region	Altitude m	Global radiation in kWh/m ²			
		1.V - 30.IX	1.VI - 31.VII	July	Annual
vojsko, SW Slovenia	1070	718.2	459.5	164.8	1147.1
Lavrovec, SW Slovenia	880	747.8	479.4	171.4	1168.2
Duh na Ostrem vrhu, NE Slovenia	910	704.1	444.0	157.3	1152.8

energy in summer and the growing season between western and eastern Slovenia at an altitude of 880-1070 m, although there are big differences in annual precipitation.

There are greater differences, however, between the Sub-Mediterranean and Continental parts of Slovenia in the radiation energy during the growing season at lower altitudes. In the immediate hinterland of the Adriatic coast (Triest Bay) in the months May-September, the energy is 50-100 kWh/m² higher than in the Continental lowland (Hočvar et al., 1982).

Above 1000 m altitude, the factors causing the differences in radiation energy are uncertain. In the summer the station on the isolated peak of Uršlja gora (1600 m) receives 398,5 kWh/m² and in the central part of the larger Julian Alps, the higher Kredarica station (2514 m), 382 kWh/m² of total radiation energy. On Mt Uršlja gora, the forest line is at 1680 m, and around Mt. Triglav, at 1800-1850 m.

3. UPPER LIMIT OF CULTIVATION OF MAIZE FOR GRAIN

Recently, this limit has been less regular than it was some decades ago, since many farmers now cultivate maize for silage. The lowest limit is in SW Slovenia. In the deep Soča valley of the Julian Alps, the limit is reduced to 500 m due to the limited radiation. The highest limit is in the NE Pre-Alpine mountains, known in Slovene geography as Pohorsko Podravje (The Pohorje Drava basin) and in the neighbouring mountains on both sides of Lavanttal in E Carinthia. There on the eastern slope of the Mt. Svinja (in German Saualpe) the cultivation of maize for grain has recently extended up to the hamlet of Lading, at an altitude of 1000 m. In Lavanttal, annual precipitation is exceptionally low: above 800 mm.

To sum up our findings and the data cited so far, we believe that no single climatic factor can be regarded as solely responsible for the different altitudes of the forest line, the upper limits of permanent agrarian settlement and maize cultivation. Climate determines the growth of plants in a complex way (Slatyer, 1973). Temperature provides an overall frame and within this, the amount of precipitation has probably the greatest influence at the altitudes studied. In this sense, the relation of temperature to precipitation is an

important indicator of the climatic conditions for plant life. In this sense Košir (1979) has studied the relation between forest associations and climate by means of Ellenberg's index Q:

$$Q = \frac{\text{Mean July temperature}}{\text{annual precipitation}} \times 1000$$

According to Košir, the differences in climate in the Mediterranean and sub-Pannonian parts of Slovenia are responsible not only for the varying altitude of the upper forest line but also, and to a still greater degree, for the different forest associations. These also differ at the forest line: being beech (*Fagus montana*) dominating in the sub-Mediterranean climate and spruce in the Continental (Lovrenčak, 1977, 1983).

4. PHENOLOGICAL PHASES IN RELATION TO ALTITUDE

In comparison with the Continental climate region, in the sub-Mediterranean climate region mean annual temperatures are 2-3° higher, relative air humidity 2-10% lower, annual sunshine duration is 200-300 hours longer and the amount of radiation energy between May and September, 30-100 kWh/m² higher. All this supports the theory of the earlier vegetational rhythm. But in the immediate hinterland of Trieste Bay, which is still subject to sub-Mediterranean climate, the natural plants are, on an average, only a few days in advance of the Continental climate. This fact is documented in table No V below.

TABLE V - Climatic elements important for phenophases in the sub-Mediterranean and sub-Pannonian Slovenia.

Station Month	Vipavsko					Bela krajina (Črnomelj)				
	Daily temp. °C		Precipitation mm	Radiation kWh/m ²	% of calms	Daily temp. °C		Precipitation mm	Radiation kWh/m ²	% of calms
	min.	max.				min.	max.			
March	3.4	12.5	105	106	19.8	0.4	11.4	80	99	40.9
April	6.6	16.9	132	134	20.8	4.7	17.5	109	126	38.7
May	10.5	21.2	127	161	21.5	8.8	22.1	99	160	43.6
June	13.9	24.7	152	164	21.7	12.4	25.8	126	159	46.0
July	14.7	27.5	115	170	21.0	13.3	28.1	118	170	50.0
August	14.7	26.7	102	156	23.7	13.3	28.1	136	153	53.8
Phenophases:										
burst into leaves of beech			12.IV.			14.IV.				
planting of potatos			9.IV.			17.IV.				
blossom of robinia			16.V.			21.V.				
crop of winter wheat			5.VII.			7.VII.				

Note: The altitude of stations near Vipava is around 106 m, that of Črnomelj 242 m. The daily minimum and maximum temperatures for Vipavsko (Ajdovščina) and Črnomelj are valid for 1931-1960 (Furlan, 1965), precipitation for Ajdovščina and Črnomelj for 1966-1975, radiation for Ajdovščina and Novo mesto for 1960-79 (Hočevar et al., 1982), % of the calms for Šlap pri Vipavi and Črnomelj for 1956-1985 (Archive...), phenological phases for Lože at Vipava and Črnomelj for 1959-1968 (Letno..., Dolinar-Lešnik, M., 1957).

In the table V a station in the Vipava Valley (Sub-Mediterranean climate) is compared with Črnomelj in Bela krajina (southern sub-Pannonian climate). In the Valley, cherry blossom appears many weeks earlier than in the Continental part of Slovenia. In summer the phenophase differences are reduced to a few days as is seen in the table. No single cited climatic element seems to be decisive in this small difference, not even that of wind (presented as the percentage of calms from all directions).

The importance of windiness for phenological rhythm increases with altitude. Solar insolation remains in the mountains nearly at the same level as in the lowlands (Gams, 1986) but the air temperature decreases with height. In windy weather the heat the plant cuticula receives from the ground diminishes more rapidly with height above ground. The loss of heat from the plant surface into the air is also greater in the colder mountainous environment. Let us compare two stations, one at the bottom of a shallow polje (Babno polje, 756 m) and the second on a sunny slope of the Karawanken (Planina pod Golico, 970 m). In the polje the daily minimum temperatures in the period from April to September is 4.8°, that is, 2.0° lower than at the higher station at Planina (6.8°). But phenological phases take place 1 - 2 days earlier at Babno polje. This fact can be attributed to the higher maximum daily temperatures (18.3°, compared with 16.7° at Planina) and especially to the more frequent calms (26.0% as compared with 20.3%).

TABLE VI - Gradient (lapse for 100 m altitudinal difference) for temperatures in Gorenjsko, upper Sava valley, 1956-1983, Komna 1956-1975.

Month Belt	1	2	3	4	5	6	7	8	9	10	11	12	1-12
<i>Daily minimum temperatures</i>													
384-695 m (Brnik-Javorje)	-0.80	-0.71	-0.67	-0.61	-0.58	-0.23	-0.48	-0.41	-0.74	-0.84	-0.51	-0.67	-0.64
695-1520 m (Javorje-Komna)	0.39	0.56	0.65	0.63	0.63	0.61	0.63	0.61	0.58	0.56	0.45	0.32	0.57
1520-2514 m (Komna-Kredarica)	0.40	0.41	0.46	0.71	0.53	0.53	0.47	0.46	0.42	0.37	0.43	0.47	0.41
384-2514 m (Brnik-Kredarica)	0.22	0.30	0.37	0.43	0.41	0.43	0.39	0.38	0.31	0.26	0.30	0.24	0.34
<i>Daily maximum temperatures</i>													
384-695 m	-0.13	0.35	0.74	0.93	1.00	0.96	0.96	0.90	0.80	0.61	0.28	-0.22	0.61
695-1520 m	0.28	0.41	0.68	0.81	0.74	0.72	0.67	0.65	0.56	0.53	0.38	0.31	0.57
1520-2514 m	0.53	0.59	0.59	0.69	0.80	0.81	0.79	0.76	0.71	0.57	0.51	0.45	0.64
384-2514	0.34	0.49	0.65	0.77	0.81	0.80	0.77	0.74	0.67	0.56	0.42	0.30	0.61

The mountainous alpine area in Slovenia is low but extremely dissected into basins and valleys. Significant temperature inversion occurs. Above this is the so-called thermal belt, where the optimal climatic condition for plant life is 120-150 m above the bottom of the basin, valley and polje. There the

minimum daily temperature is higher and the maximum temperature lower or the same, higher mean daily temperatures for 0.9-1.5° and sunshine duration longer, this being reduced in the basins by frequent fog (Gams, 1986). Anko (1981) has also illustrated the thermal belt by measurements taken in the period 1979-1981 in the valley of the Drava. The highest mean daily temperatures and highest circumglobal radiation in joules/day were recorded at an altitude of 700 m, that is 300 m above the valley bottom (Table VI).

The vertical temperature lapse (gradient) in the air layer just above ground level (and not at 2 m above as at meteorological stations) is greater in the mountains than in the lowlands. On a sunny day it is greatly influenced by windiness. Its strength and frequency is dependant on the shape and elevation of the mountain as well. This was supported by research carried out on the sunny side of Mt Pohorje. Questions put to the farmers living there revealed that the retardation of the phenological rhythm of cherry blossoming, the hay harvest and the crop harvest is, up to an altitude of 400-600 m above the valley bottom, only 1 - 3 days. The delay increases to 7-10 days at an altitude of 900-1000 m while are 1100 m, it is already more than 11 days (fig. 3). These thresholds are probably controlled by the general shape of the mountain. Above this altitude, there is nothing but the central ridge of the Drava-Sava-watershed, which means a rapid increase of wind strenght.

In the Central Alps in Slovenia, above 800 m of altitude, level surfaces are usually no longer cultivated for cereals and the fields occur only on the steep sunny slopes (Medved-Gams, 1968).

The likely forest line on Mt Pohorje, which is broader than the Karawanken peaks, is at the altitude of 1600 m. This line is higher on the neighbouring isolated peaks of Uršlja gora (1640-60 m) and Peca (1840-1940 m).

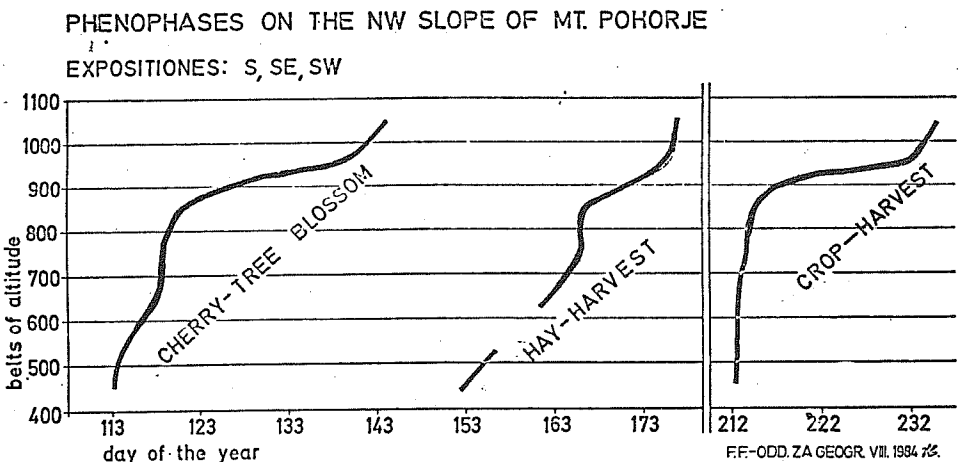


FIG. 3 - Phenophases on the Mt. Pohorje.

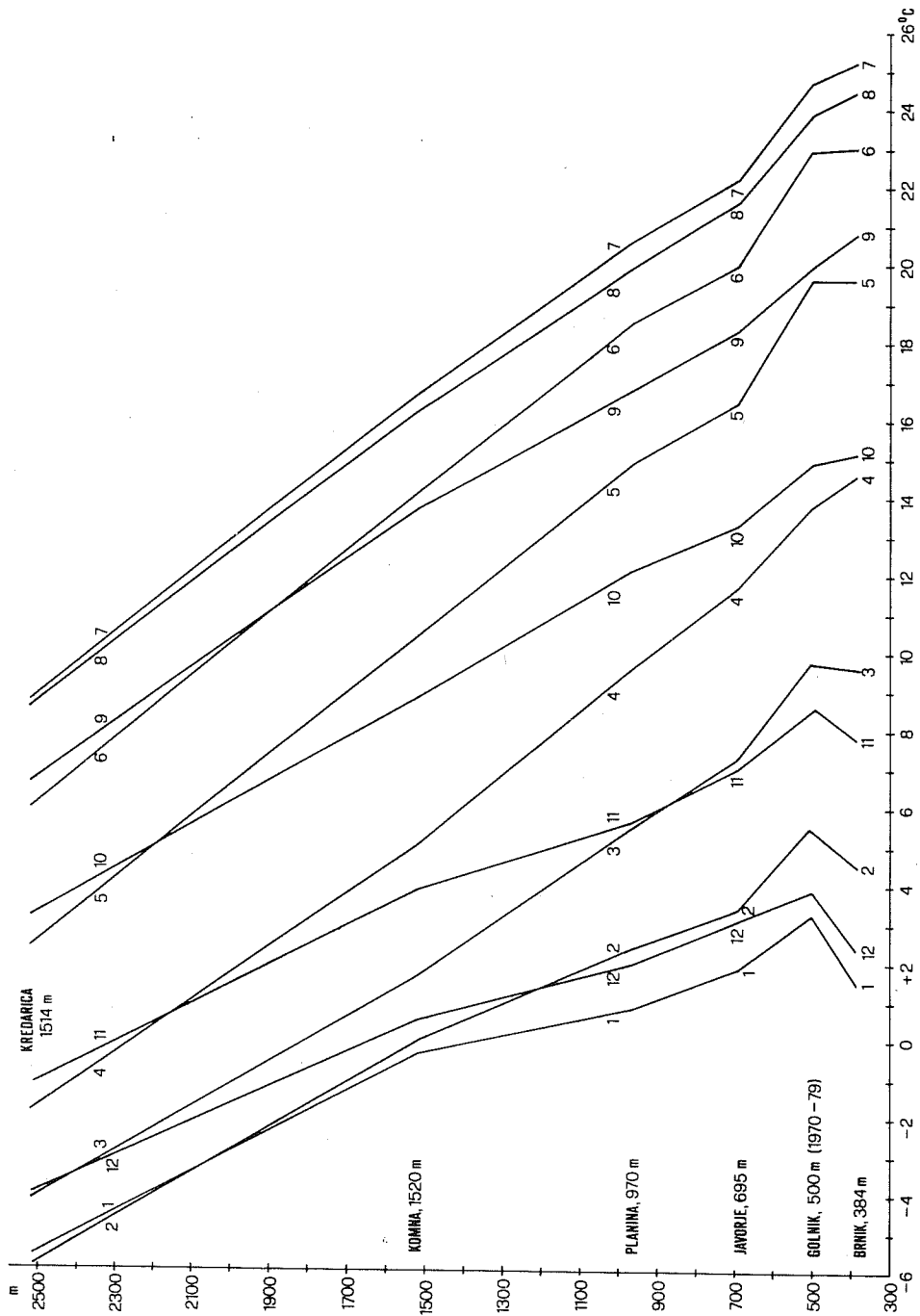


FIG. 4 - Daily maximum temperatures in the altitudes of the upper Sava basin.

These variations are contrary to what the theory of «Massenerhebung» (mass elevations) might lead one to expect. The measurements of the annual growth of the terminal shoots of trees at the forest line at these places have shown the great influence wind strength has on tree growth. From this point of view, Massenerhebung effect is seen to derive from the different type of air circulation and wind speed and frequency as well (Gams, 1977).

On average, in Slovenia, the delay of phenophases above the thermal belt amounts to about 10 days for every 300 m altitude. This correlation can be attributed to the more specific diminishing of daily maximum temperature with altitude. But these maximum temperatures are relatively warmer in the fall at higher altitudes than in the lowlands (fig. 4). This is due to the effect of the relatively warmer, higher, oceanic air masses of westerly flow from the Atlantic and Mediterranean. By contrast, in spring these higher air masses are relatively colder than in the lowland air which has already been heated by the sun. In the lowlands, May temperatures are 4° higher than those occurring in October, but colder at the altitude of the highest Yugoslav station, Kredarica (2514 m). April temperatures are, even in the lowlands, 6° warmer than November figures, but colder at Kredarica. On the other hand, September is colder than June in the lowlands and conversely above 1800 m.

The lapse rate (gradient) of daily minimum temperatures is more evenly distributed during the year and within altitudinal belts. It is shown in figure 5. The dark rectangles indicate the altitude which has the same monthly minimum temperatures as occur at the bottom of the Ljubljana basin (the coldest station being at Brnik) The lapse rate between Brnik and the upper level of the thermal belt (Javorje, in the Poljanska Sora Valley) is negative throughout the year: at Javorje (695 m) every month has lower minimum daily temperatures. The greatest negative differences are in September, January and February and the smallest in June. Above the thermal belt, the minimum daily temperatures decrease in every month in the 695-1520 m belt for a greater degree than in the 1520-2514 m belt. The relation of lowland to highland is, as regards minimum daily temperatures, nearly the same as for maximum daily temperatures.

The maximum and mean daily temperatures (the latter are calculated in Yugoslavia using the equation $\frac{7^h + 14^h + 2 \times 21^h}{4}$) are 4° higher in the fall at an altitude of 2500 m than in the spring months, while in the lowlands the difference is 0.5° (maximum temperatures are equal there).

The more ocean-influenced climate of the mountains causes a delay in the onset of the growing season and shifts it into the second half of the year. This fact certainly has a great influence on the delay of plant phenophases as well (see data relating to Gorenjsko, Gams, 1981), but this relationship has not yet been studied. What is known is the damage caused by early snow cover in the fall to cereal cultivation at the highest settlements (Gams, 1959).

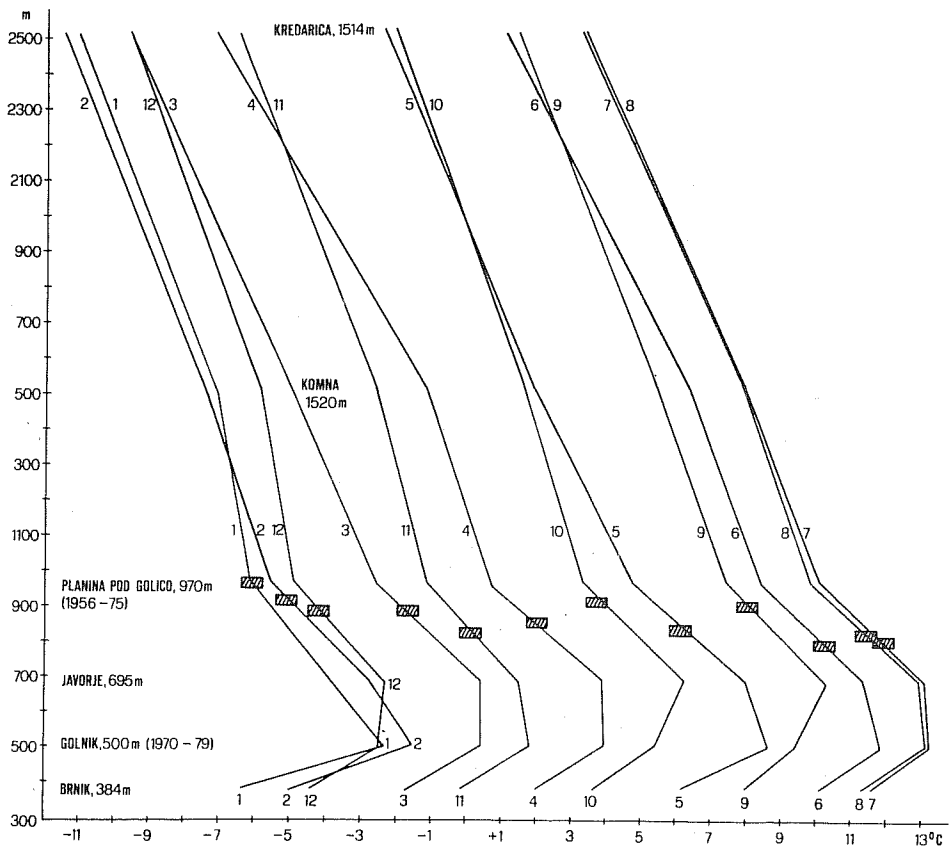


FIG. 5 - Daily minimum temperatures in the altitudes of the upper Sava basin.

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