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Relation between the height of *Larix kaempferi* and some climatic characteristics in Poland

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Abstract: Japanese larch (*Larix kaempferi* Sarg.) is one of the most frequent exotic species in Polish woodlands. The basic object of research comprised 60 stands of the studied species, located mainly in the northern and western parts of Poland. The growth results for the studied species, evaluated on the basis of the average height (h_{g55}), were compared with data describing the local climate and the stand location within the botanical and climatic zoning. The results confirm the opinion that the Japanese larch prefers a climate of maritime character and generally shows high degree of flexibility regarding its climatic requirements (very large differences between the growth conditions in the studied area and the country of origin). The dependence between the growth results and precipitation is however lower than expected. The most interesting results include the relatively clear connection between the height of the larch stands and the Degórski's (1984) 'floristic' 'K' (continentality) index.

Additional key word: continentality, climatic zoning, introduction, acclimation, temperature, precipitation

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Introduction

As reported in earlier publications (Filipiak 1996, 1999) Japanese larch is one of the most frequent exotic species in Polish woodlands. In some provinces, for example in Pomerania, it is more widespread than the native European larch (*Larix decidua* Mill.).

The natural climate of the stands of the Japanese larch is featured by a precipitation of 1500–2500 mm per year, of which the major part is occurred during the vegetation period. During this period it is practically impossible to note a month during which the precipitation is lower than 100 mm (Schober 1953, Lindquist 1955, Bellon et al. 1977), whereas in winter falls to 50 or even 20 mm per month, depending on the stand location (Schober 1953). This type of precipitation is also related to a different distribution of air humidity than in Europe where the relative air humidity is at its highest usually in winter, whilst in Japan the maximum values are observed from July to September. The temperatures of the natural sites of the *Larix kaempferi*, range from –1 to +5°C in January, and from +18 to +20°C in August. This shows that the temperature conditions of the Japanese larch stands in Europe and in Japan do not differ as significantly as those related to precipitation.

In Japan, which is featured by much rainfall, the precipitation factor in the cultivation of the Japanese larch is not treated with great concern (Matsui 1980, Ogawa 1987) however in other areas, particularly in Europe, the level of precipitation is decisive to the growth of this species. Practically all the European authors who deal with the issue of cultivating the Japanese Larch emphasise that it grows well in an oceanic climate featured by a large amount of precipitation and high air humidity. According to Eggert

(1987), the Japanese larch for optimal growth requires precipitation of at least 800–1000 mm per year. Schober (1953) believes that in the poorer "pine-type" areas the *Larix kaempferi* can only be grown in coastal regions (up to the Bremen – Lineburg line in Germany). According to this author, the southern cultivation limit of this tree responds to the northern reach of vineyards. Apart from the general precipitation level, the Japanese larch is also sensitive to its uneven distribution during the year and the recurrent summer drought periods (Eisenreich 1956, Eggert 1987, Petri 1987, Otto 1987, Wachter 1987). As far as the temperatures of the air are concerned, it seems that the requirements of the *Larix kaempferi* are significantly lower than those concerning precipitation and humidity. These factors are mentioned by Zimmermann (1987), who believes that, at least in the conditions of Hessen (Germany), the humidity of the air is more important to the Japanese larch than the heat total. Also Edwards (1957) thinks that in British conditions the air temperatures do not have a significant effect on the growth of the Japanese larch.

Comprehensive measurements performed in over 60 localities have shown that in Polish conditions the Japanese larch can reach growth parameters exceeding I stand quality class according to tables used in its country of origin (Filipiak 1999).

Properly managed forest stands of Japanese larch in Poland can compete in trees quality with stands of native larches. The alien species is more susceptible to a lower stand density and exposure to strong winds. There its no correlation between forest stand quality and growth dynamics (Filipiak and Pilarek 2003).

This article presents the evaluations concerned of relation between average height of Japanese larch stands and the climatic conditions. The data come from forest stands located mostly in north-western Poland, where this species comes up most frequently.

Materials and methods

The basic object of research comprised stands of the studied species located mainly in the northern and western parts of Poland, described in detail in the works of Filipiak (1996, 1999) Filipiak and Pilarek (2003). The investigation in each stand included height measurements of 25–30 trees in order to draw height curve. The measurements were made using a Matusz hipsometer with an accuracy of up to 0.5 m for each tree, from two opposite sides. The real height was calculated as the mean value of both measurements. Among the many factors taken into account in the evaluation of the growth results of a studied tree, the most important one was its height responding to the mean surface of the breast height diameter of the tree stand (Bruchwald 1999). In order to enable better comparison of the particular tree stands, their basic parameters, including the height, were brought down to one age of 55 years (an age close to the average one of the studied objects). This was accompanied by accepting the principle that the course of the growth of the particular stands was close to the course presented in Wiedemann's and Schober's tables (1957), a fact determined during previous studies (Filipiak 1999). The growth results for the studied species evaluated on the basis of the aforementioned height (h_{g55}) were compared with data that described the local climate and the stand location within the botanical and climatic zoning (Table 1). The respective data were obtained by comparing the location of the tree stands with the distribution of the particular values on applicable maps (see explanatory notes to Table 1). The t test and the correlation coefficient were used in the statistical analysis of the results.

Results

Table 1 contains the more significant data describing the climatic conditions of the particular cultivation sites of the *Larix kaempferi* in Poland in addition to data concerning the location of the stands within the various botanical and climatic divisions of Poland.

Table 2 presents the corre1ation coefficient (r) and its square (r^2) between the mean height of

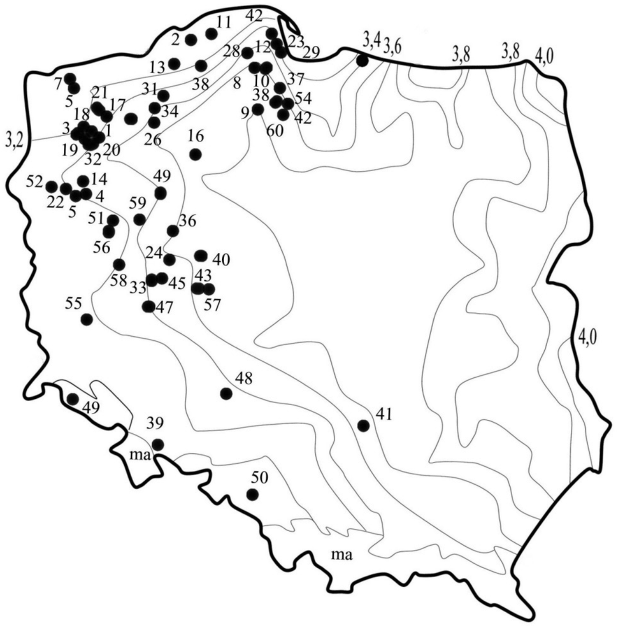

Fig. 1. Geographical distribution of examined Japanese larch stands and values of Degórski's (1984) continentality index "K" (calculated on the basis of interpretation of floristical composition of *Querco-Carpinetum* association by Ellenberg's method)

Labels: 3.2–4.0 outside the map – values of continentality index, labels: 1–60 on the map – Japanese larch stands numbers in table 1, ma – mountains area, without *Querco-Carpinetum* association

Table 1. The climatic conditions of the *Larix kaempferi* stands in Poland

No. of plot	Forest district	Compartment	Average age of stand (years)	h_{g55} (m)	Forest site type	Average air temperature (°C)			Annual air temp. amplitude (°C)	Average precipitation sum (mm)		Precipitation index by Lang	Water saturation deficit of air (hPa)	Region of Poland by			Zone of continentality by	
						year	I	VII		year	V–X			IBL	Szafer	Heintze & Schraiber	Borowiec	Degórski
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Dobrzany	89 l	62	31.3	Lśw	8.1	–1.4	17.8	19.5	590	360	72.8	5.3	I 2b	5b	6b/7a	II	3.2
2	Leśny Dwór	598 f	57	30.6	Lśw	7.3	–1.5	16.8	18.7	730	440	100.0	4.0	I 4a	2	7a	I	3.2
3	Dobrzany	71 p	62	30.5	LMśw	8.1	–1.4	17.8	19.5	590	360	72.8	5.3	I 2b	5b	6b/7a	II	3.2
4	Kłodawa	345 i	66	30.1	LMśw	8.2	–1.6	17.9	20.1	550	340	67.1	5.6	I 3b	6a	6b	III	3.3
5	Gryfice	380 h	58	29.8	LMśw	8.0	–1.2	17.4	18.7	640	400	80.0	4.0	I 2b	2	7b	II	3.2
6	Zapoworo	141	67	29.7	Lśw	7.3	–2.8	17.4	20.9	650	420	89.0	4.6	I 7b	5d	6b	II	3.4
7	Gryfice	626 g	62	29.7	LMśw	8.0	–1.3	17.4	18.7	640	400	80.0	4.0	I 2b	2	7b	II	3.2
8	Kolbudy	132 c	76	29.2	LMśw	7.0	–2.5	17.0	20.0	610	410	87.1	4.4	I 5c	5c	6b	II	3.4
9	Wirty	61 s	91	29.1	LMśw	7.4	–2.9	17.4	20.8	620	410	83.8	4.8	I/III 1	5c	6b	III	3.5
10	Kolbudy	130 c	46	29.0	Lśw	7.0	–2.5	17.0	20.0	610	410	87.1	4.4	I 5c	5c	6b	II	3.4
11	Dymnica	145 d	58	28.9	Lśw	7.3	–1.6	16.8	18.7	700	430	95.9	4.0	I 4a	2	7a	I	3.2
12	Gdańsk	134 b	47	28.8	Lśw	7.4	–2.0	17.1	19.8	600	400	81.1	4.1	I 5c	5c	7a	II	3.3
113	Warcino	173 b	61	28.7	LMśw	7.0	–2.2	16.8	19.0	730	430	104.3	4.2	I 5a	2a	6b/7a	I	3.2
14	Barlinek	149 a	59	28.6	LMśw	8.1	–1.6	17.9	20.0	570	340	70.4	5.5	I 3b	5a	6b/7a	III	3.3
15	Kłodawa	381 b	66	28.5	LMśw	8.2	–1.6	17.9	20.1	550	340	67.1	5.6	I 3b	6a	6b	III	3.3
16	Złotów	66 g	59	28.5	Lśw	7.5	–2.3	18.0	21.1	570	360	76.0	5.5	III 2b	6b	6b	III	3.5
17	Resko	263 a	52	28.3	LMśw	8.0	–1.4	17.5	19.4	660	400	82.5	5.1	I 4a	5b	7a	I	3.2
18	Dobrzany	140 i	63	28.0	Lśw	8.1	–1.4	17.8	19.5	600	370	74.1	5.3	I 2b	5b	6b/7a	II	3.2
19	Dobrzany	96 a	55	28.0	LMśw	8.1	–1.4	17.8	19.5	590	360	72.8	5.3	I 2b	5b	6b/7a	II	3.2
20	Dobrzany	105 i	55	28.0	LMśw	8.1	–1.4	17.8	19.5	590	360	72.8	5.3	I 2b	5b	6b/7a	II	3.2
21	Resko	252 a	54	27.6	BMśw	8.0	–1.4	17.5	19.4	660	400	82.5	5.1	I 4a	5b	7a	I	3.2
22	Barlinek	137 b	47	27.5	LMśw	8.1	–1.6	18.0	20.0	570	340	70.4	5.5	I 3b	5a	6b/7a	III	3.3
23	Gdańsk	141 d	24	27.5	BMśw	7.4	–2.0	17.1	19.8	590	390	79.7	4.1	I 5c	5c	7a	II	3.3
24	Zwierzyniec	6 f	21	27.5	Lśw	8.4	–1.9	18.6	21.0	530	330	63.1	>6	III 7b	7c	6b	III	3.5
25	Świdwin	513 f	52	27.4	BMśw	7.6	–1.9	17.3	20.0	670	390	88.2	4.2	I 5b	5b	6b/7a	I	3.3
26	Szczecinek	154 d	80	27.4	Lśw	7.3	–2.3	17.0	20.0	670	410	91.8	4.9	I 5b	5b	6b	II	3.4
27	Warcino	173 d	33	27.3	LMśw	7.0	–2.2	16.8	19.0	730	430	104.3	4.2	I 5a	2a	6b/7a	I	3.2
28	Kartuzy	214 c	69	27.3	LMśw	6.5	–2.9	16.5	19.9	630	410	96.9	4.4	I 5c	5c	6b	II	3.5
29	Gdańsk	151 a	32	27.3	Lśw	7.5	–2.0	17.1	19.8	600	400	80.0	4.1	I 5c	5c	7a	II	3.3
30	Głęboki Bród	5 f	53	27.0	Lśw	6.4	–5.0	17.7	23.2	580	390	90.6	4.5	II 4a	22b	5b	III	4.0
31	Szczecinek	96 a	45	27.0	LMśw	7.3	–2.3	17.0	19.9	650	400	89.1	5.0	I 5b	5b	6b	II	3.4
32	Dobrzany	984 n	55	26.8	LMśw	8.1	–1.4	17.9	19.6	580	360	71.6	5.3	I 2b	5b	6b/7a	II	3.2
33	Kościan	126 a	55	26.7	Lśw	8.2	–1.8	18.6	20.9	530	330	64.6	>6	III 7b	7c	6b	III	3.5
34	Szczecinek	3 j	52	26.7	LMśw	7.3	–2.3	16.9	19.8	670	410	91.8	4.8	I 5b	5b	6b	II	3.4

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
35	Dretyń	32 d	48	26.6	LMśw	7.0	–2.5	16.7	19.1	710	440	101.4	4.1	I 5a	5b	6b/7a	I	3.2
36	Łopuchówko	171 f	58	26.6	LMśw	8.2	–1.9	18.5	21.1	530	340	64.6	>6	III 7b	7c	6b	III	3.5
37	Starogard	133 g	48	26.5	LMśw	7.6	–2.6	17.5	20.9	580	390	76.3	4.7	I 5d	5c	6b	III	3.5
38	Starogard	70 b	48	26.2	LMśw	7.6	–2.6	17.5	20.9	580	390	76.3	4.7	I 5d	5c	6b	III	3.5
39	Wałbrzych		51	26.2	LMG	5.9	–3.0	15.8	19.4	810	520	137.3		VII 2d	F	6a	I	
40	Czerniejewo	28 k	53	26.1	LMśw	8.2	–2.1	18.5	21.2	510	310	62.2	>6	III 7c	7c	6b	III	3.5
41	Jędrzejów	17 a	86	26.0	LMśw	7.4	–3.5	17.9	22.0	630	400	85.1	>6	VI 9a	17d	6b	II	3.7
42	Gdańsk	206 b	52	25.8	LMśw	7.4	–2.0	17.1	19.8	600	400	81.1	4.1	I 5c	5c	7a	II	3.3
43	Jarocin	300 c	53	25.8	LMśw	8.2	–2.1	18.6	21.1	540	340	65.8	6.0	III 7b	7c	6b	III	3.5
44	Sarbia	196 g	55	25.7	LMśw	7.8	–2.2	18.2	21.0	560	360	71.8	5.8	III4b	7a	6b	III	3.4
45	Kościan	148 d	48	25.6	LMśw	8.2	–1.8	18.6	20.9	530	330	64.6	>6	III 7b	7c	6b	III	3.5
46	Wisła	29 b	94	25.6	LMG	6.5	–4.5	16.5	21.0	1200	700	184.6		VIII 1	D	6b	I	
47	Karczma Borowa	16 d	89	25.5	LMśw	8.2	–1.6	18.6	20.7	550	340	67.1	6.0	III 7b	7c	6b	III	3.5
48	Namysłów	87	50	25.4	LMśw	8.0	–1.8	18.5	21.2	580	390	72.5	>6	V 2g	11b	6b	II	3.4
49	Szklarska Poręba	208 b	74	27.9	LMG	6.5	–2.9	15.5	18.0	950	580	146.1		VII 1c	Fa_1	6b	I	
50	Rybnik	2 c	49	24.6	LMśw	8.0	–2.5	18.0	21.3	690	410	86.2	6.0	V 6b	11b	6b	I	3.2
51	Międzychód	206 d	43	24.2	BMśw	7.9	–1.7	17.8	20.5	560	350	70.9	5.9	III 4b	7a	6b	III	3.3
52	Myślibórz	369 a	42	24.0	BMśw	8.2	–1.4	18.1	19.9	560	340	68.3	5.6	I 3b	5a	7a	III	3.3
53	Starogard	70 b1	48	23.6	BMśw	7.6	–2.6	17.2	20.9	580	410	76.3	4.8	I 5d	5c	6b	III	3.5
54	Antonin	179 j	57	23.6	BMśw	7.8	–2.2	18.0	21.3	610	370	78.2	6.0	III 9	7e	6b	III	3.5
55	Chocianów	192 b	51	23.6	BMśw	9.3	–1.4	18.2	20.3	560	370	60.2	6.0	V 1b	7b	7a	III	3.3
56	Międzychód	207 d	49	23.2	BMśw	7.9	–1.7	17.8	20.5	560	350	70.9	5.9	III 4b	7a	6b	III	3.3
57	Jarocin	302 r	49	22.9	LMśw	8.2	–2.1	18.6	21.1	540	340	65.8	6.0	III 7b	7c	6b	III	3.5
58	Wolsztyn	55 a	55	22.4	BMśw	8.0	–1.9	18.0	20.5	530	330	66.3	>6	III 6b	7c	6a	III	3.4
59	Wronki	183 d	46	17.4	Bśw	7.8	–2.1	17.8	20.7	540	350	69.2	6.0	III 4b	7a	6b	III	3.4
60	Starogard	71 p	48	15.1	Bśw	7.6	–2.6	17.2	20.9	580	410	76.3	4.8	I 5d	5c	6b	III	3.5

Explanatory notes

Number of column	Description
1–4	description as in the table
5	height corresponding to average basal area of main crop at the age of 55 years
6	forest site type: Lśw (fresh deciduous forest). LMśw (fresh mixed deciduous forest). BMśw (fresh mixed coniferous forest). Bśw (fresh
7	average air temperature throughout a year (Paszyński. Niedźwiedź 1999)
8	average temperature in January (Paszyński. Niedźwiedź 1999)
9	average temperature in July (Paszyński. Niedźwiedź 1999)
10	annual air temperature amplitude
11	average precipitation sum in the year
12	average precipitation sum in the summer half year
13	natural forest region according to Mroczkiewicz's division modified by IBL (Trampler et al. 1990)
14	region in Szafer's geobotanical zoning of Poland (Szafer and Pawłowski 1972).
15	region and subregion of the plant's winter resistance according to Heinze's and Schreiber's (1984) division.
16	water saturation-deficit of air [hPa]
17	zone of continentality by Borowiec (1965)
18	continentality extent index "K" calculated on the basis of interpretation of floristical composition of *Querco-Carpinetum* association by Ellenberg's method

Table 2. The correlation coefficient (r) and its square (r^2) between the mean height of 55-year-old *Larix kaempferi* stand growing on the site LMśw (fresh mixed broadleaved forest) and the different climatic indices

Trait	Correlation coefficient	Square (r^2)
average air temperature throughout a year	0.08	0.00
average temperature of January	0.47	0.22
average temperature of July	–0.50	0.25
average annual air temperature amplitude	–0.77	0.59
average precipitation sum in the year	0.49	0.24
average precipitation sum of summer half year (V–X)	0.34	0.12
average water saturation–deficit of air [hPa]	–0.49	0.24
zone of continentality by Borowiec (1965)	–0.44	0.19
continentality index "K" calculated on the basis of interpretation of floristical composition of *Querco–Carpinetum* associations by Ellenberg's method	–0.74	0.55

55-year-old *Larix kaempferi* stand growing on the site 'LMśw' (fresh mixed broadleaved forest) and the different climatic indices. In the analysed data 'LMśw' is the most frequent and representative site type.

There is a statistically significant difference between the growth results of the *Larix kaempferi* in natural forest regions I and III (according to Mroczkiewicz's division modified by IBL, Trampler et al. 1990). A similar difference is observed in the case of regions specified as 1 and 2 in Szafer's geobotanical zoning of Poland (Szafer and Pawłowski 1972).

What is worth noting in the presented data is the fact that there is no correlation between the growth of the Japanese Larch and the average air temperature values throughout a year. Middle level correlations are observed in the case of precipitation, the water saturation-deficit of air, the average temperature of January and the average temperature of July. A relatively high correlation is shown between the continentality index and the annual air amplitude. It is also worth noting that the growth in height of the Japanese Larch is better correlated to the zones of the continental extent determined on the basis of Degórski's (1984) "floristic" "K" index than to Borowiec's (1965) division based on climatic data, i.e. the ratio of the total annual precipitation to the amplitude of average monthly temperatures.

Discussion

The data in Table 1 suggest a slightly better growth in the plant winter resistance zones numbered lower according to Heinze and Schreiber's (1984) classification. Table 2 presents a relatively low, but significant correlation between the height of the forest stands (h_{g55}) and the average temperature in January. On the other hand, the data in Table 1 also prove the satisfactory growth of the studied species on the sites where the temperature in January is much lower than that observed in northern and western parts of Poland. This refers to forest stands from the forest districts Szklarska Poręba, Wałbrzych, Wisła and Głęboki Bród, where the average January temperatures are –2.9, –3.0, –4.5 and –5.0°C, respectively. However, despite the higher level of precipitation, Larch growth in these stands is usually slower than in the forest stands of northwestern Poland.

Along with the decrease in average monthly temperatures in winter, the duration of periods with air frost is usually extended (e.g. Bac and Rojek, 1979). The lack of phenological adaptation to the periods of air frost may be the cause of damage to the trees of *Larix kaempferi*. Freezing on plot no. 46 (Wisła) is mentioned by Chylarecki (2000). Damage caused by frost is not, however, strong enough to lead to the death or significant injury of the well-regenerating Japanese Larch; it can, nonetheless, slow down its growth. In Northern France (Schober 1953), in Germany (Eisenreich 1956; Dittmar et al. 1978), and Latvia (Ramats 1980), infrequent damage caused by late frost has been observed. According to Olaczek (1986), who quotes Elenberg, late frost in May in Munich caused the necrosis of young needles of Japanese Larch at the temperature of –6°C, of European Larch at –8°C, and of Norway spruce at –4°C. In Southern Sweden (Linquist 1955), Finland, Western Russia (Schober 1953), Latvia (Ramats 1980) and Lithuania (Biehler 1935), such damage was noted from the onset of early air frost.

The relatively high value of the correlation coefficient in Table 2 for the average temperature in July is probably related to the effect of summer temperatures on air humidity as well as the water content of the soil.

The collected data showed lower than expected (albeit significant) relationships between the height growth of the Japanese Larch and precipitation. This seems to be related to the fact that, apart from precipitation, air and soil humidity in a given locality is strongly affected by its physiography, i.e. depression or elevation, and large or small forest complex.

A significant correlation in the case of water saturation deficit in the air (Table 2) draws attention to the important role of this factor in the course of tree growth. Another noteworthy factor is the annual air temperature amplitude, with a high value of the correlation coefficient. In my opinion, this is probably not directly related to the role of the annual temperature difference in tree growth, but to connections between the amplitude and the degree of continentality.

The effect of climate on the growth of the studied species is very complex. More obvious connections are observed when comparing growth to climatic conditions, expressed as Degórski's (1984) K index (degree of continentality) as well as the location in botanical and climatic zones. When studying the more specific variables, i.e. temperature and precipitation, the correlations between the climatic data and the growth results are less clear.

On the whole, our results confirm the opinion that the Japanese Larch prefers maritime climates, and generally shows a high degree of flexibility in its climatic requirements (very large differences between growth conditions in the study area and the country of origin). The dependence between the height growth and precipitation or Lang's (Paszyński and Niedźwiedź 1999) hydrothermal coefficient in particular, is lower than expected. The most interesting results include the relatively strong connection between the height of the Larch stands and the amplitude of air temperature, as well as Degórski's (1984) floristic K index (reflecting the degree of continentality). It is commonly assumed that in Polish conditions, the current composition of natural plant communities is determined by climatic conditions and processes of migration, uninterrupted since the end of the last glaciation. The close connection of the K index to the air temperature amplitude and the growth rate of the introduced Japanese Larch, suggest that at present the main factor affecting the formation of the natural flora (in this case, fresh mixed broadleaved forest) is the climate. Degórski's K index so far has been regarded rather as a curious detail, whereas in the light of this study, it deserves more emphasis as an important element of the botanical and climatic zonation of this part of Europe.

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