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VEGETATION AND CLIMATE IN POLAND IN THE 1990S: VARIATIONS OF THE NORMALISED DIFFERENCE VEGETATION INDEX, AIR TEMPERATURE, SUNSHINE AND PRECIPITATION

Abstract: Climatic variation of the growing seasons during the 1990s was examined using the 10-day values of the normalised difference vegetation index (NDVI) for five regions in Poland. In order to compare the NDVI values with climatic conditions, multiple correlation coefficients and regression equations for the 10-day means of NDVI on the one hand, and temperature, precipitation, and sunshine anomalies on the other, in the period between April and September, were calculated. The mean temperatures and the duration of the growing seasons in the 1990s were compared to those for the period between 1951 and 1990.

Key words: climate variations, vegetation, NDVI.

The purpose of the study reported was to define the influence of climatic conditions on the development of vegetation during the growing season in Poland.

The state of development of vegetation was determined on the basis of the normalised difference vegetation index (NDVI) obtained from the satellite imagery NOAA, registered by the AVHRR scanners. The NDVI data, encompassing the period between 1992 and 1998 (except for 1994) were made available by the Institute of Geodesy and Cartography in Warsaw, which collaborates in gathering of these data with the Canadian Remote Sensing Centre in the framework of the System of Evaluation of Conditions for Plant Growth in Poland (Bochenek 1999).

The NDVI is defined as the quotient of the streams of radiation registered by the satellite in the visible light range for the band of 0.58-0.68 mm and in the near infrared band of 0.72-1.1 mm, or, more precisely:

$$NDVI = \frac{nearIR - visible}{nearIR + visible}$$

It was shown that NDVI is strictly correlated with the leaf area index (LAI), net primary production (NPP), see White et al. (1992), and the biomass volume (Struzik 1999).

Since the development of plant vegetation is regulated by the light, thermal, and humidity conditions, relations were studied between the NDVI and insolation, temperature and precipitation during the growing season. The measure of the actual influence of the meteorological elements on the value of the NDVI is the correlation of the deviations of the values of these variables during particular growing seasons from their average “climatic pattern”, represented by the long term means. In addition, relations between the development of vegetation and weather conditions change along with the consecutive phases of the growing season. In order to account for these changes, the growing seasons analysed, encompassing the period between April 21st and September 30th, were divided into phases of approximately 40 days each, namely: April 21st – May 31st (I), June 1st – July 10th (II), July 11th – August 20th (III), and August 21st – September 30th (IV).

With the 10-day averages for NDVI, air temperature (T), insolation (S), and precipitation (R) being available for all the phases of the growing season, the highest and the lowest values of these variables were determined for the 6-year period considered, and then, analogously as in Bochenek (1999), the following normalised indicators were calculated for each phase in consecutive years:

1. Indicator of vegetation condition:

$$VCI = 100 \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

2. Thermal indicator:

$$TI = 100 \frac{T - T_{min}}{T_{max} - T_{min}}$$

3. Sunshine indicator:

$$SI = 100 \frac{S - S_{min}}{S_{max} - S_{min}}$$

4. Precipitation indicator:

$$RI = 100 \frac{R - R_{min}}{R_{max} - R_{min}}$$

Indicators defined in this manner take in the particular phases of the season between April and September the values between 0 and 100.

Multiple regression equations for VCI (TI, RI, SI) were identified separately for each phase of the season (I through IV) and for five selected regions of Poland: the vicinity of Szczecin – representing the North-West (NW) of Poland, Wrocław (SW), Suwałki (NE), Przemyśl (SE), and Łódź (centre) – see Fig.1. Equations were identified on the basis of 24-element samples (four 10-day periods from six years). The regression coefficients obtained and the corresponding correlation coefficients are shown in Table 1.

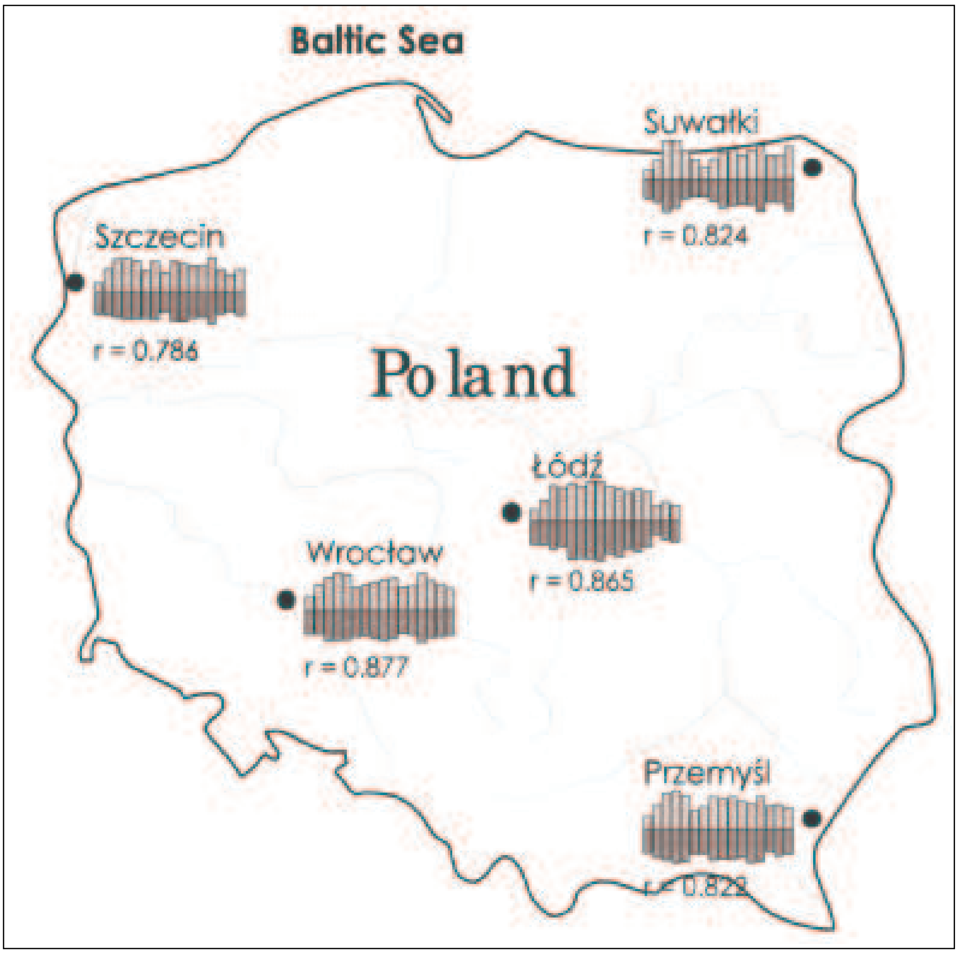

Fig. 1. The six-year averages of the observed values for 10-day periods (April 21st – September 30th) of the NDVI index (upper parts of the histograms), the values of the NDVI estimated on the basis of sunshine, precipitation, and temperature (lower part of the histograms), as well as their correlation coefficients (r).

Tab. 1. Coefficients of the multiple regression equations and correlation coefficients (r) of the VCI index with sunshine (SI), precipitation (RI), and temperature (TI) in the four phases of the growing season; b – constant (phase I: April 21st – May 31st; phase II: June 1st – July 10th; phase III: July 11th – August 20th; phase IV – August 21st – September 30th) (x - coefficients significant at the level of 0.05).

	I					II				
	SI	RI	TI	b	r	SI	RI	TI	b	r
Szczecin	0.86	0.31	-0.21	14.84	0.49	0.77	-0.02	-0.70	49.73	0.57
Suwałki	0.25	0.33	0.67	-8.15	0.64x	0.62	0.52	-0.08	-10.58	0.37
Łódź	0.24	0.19	0.25	23.82	0.39	0.16	0.29	0.03	66.69	0.27
Wrocław	0.78	0.46	-0.21	15.13	0.54	0.41	0.22	-0.10	39.56	0.31
Przemyśl	0.26	0.44	0.32	19.40	0.54	0.76	0.36	-0.02	15.08	0.66x

	III					IV				
	SI	RI	TI	b	r	SI	RI	TI	b	r
Szczecin	0.76	0.15	-0.64	57.60	0.64x	0.84	-0.08	-0.23	29.01	0.61x
Suwałki	0.50	0.22	-0.54	53.71	0.54	0.93	0.09	-0.53	49.64	0.56
Łódź	0.53	0.35	-0.48	57.50	0.57	1.20	0.33	-0.59	13.62	0.64x
Wrocław	0.35	0.43	-0.47	55.63	0.63x	0.58	0.12	-0.04	32.49	0.43
Przemyśl	0.49	0.17	-0.28	48.30	0.43	0.63	-0.11	-0.12	35.47	0.71x

Coefficients corresponding to the variables RI and TI change their sign depending upon the phase of the growing season, and only the relation between the VCI index and insolation is steadily positive. Precipitation has mostly a positive influence on the value of the VCI index. Temperature increase causes a decrease of the VCI value in phases III and IV of the season, while in phase I its influence is positive in the eastern part of the country, and negative in the western part. The strength of the relation of VCI with the meteorological variables distinctly increases in the second half of the season, and so, for instance, for the area of Przemyśl, the correlation coefficient attains in phase IV of the season the value of 0.71 (Tab. 1).

Using the four regression equations (phases I – IV) one can estimate the value of the VCI index during the whole April – September season. Coefficients of correlation between the estimated and the observed values of VCI range between 0.49 (Wrocław) and 0.66 (Łódź), and change significantly in particular years (Tab. 2). The course of the estimated and observed values of VCI for the region of Łódź, where the correlation turned out to be the strongest, is shown in Figure 2.

In the search for the more precise dependence of the NDVI index upon the meteorological elements, the coefficients were also calculated of regression equations and correlation on the basis of the deviations of the NDVI, temperature, sunshine, and precipitation, from the average values in particular 10-day periods. These coefficients are given in Table 3. These correlations – as can be seen from the example of Łódź – do not differ significantly from the correlation defined on the basis of deviations (of indices) for the scale of the whole phases of the season (i.e. four 10-day periods each).

Tab. 2. Correlation coefficients (R) between the observed and the estimated values of the VCI in the consecutive years and in the whole 6-year period between 1992 and 1998 (R_6).

	R						
	1992	1993	1995	1996	1997	1998	R_6
Szczecin	0.73	0.48	0.72	0.39	0.44	0.61	0.58
Suwałki	0.59	0.38	0.70	0.46	0.72	0.66	0.58
Łódź	0.79	0.27	0.84	0.54	0.90	0.72	0.66
Wrocław	0.38	0.46	0.62	0.65	0.70	0.16	0.49
Przemyśl	0.59	0.67	0.52	0.72	0.72	0.35	0.59

It is interesting to note that during the time period analysed there has been a quite systematic change of the difference between the observed and estimated values of the NDVI. Thus, in the first two years the measured values of NDVI were lower than the ones estimated on the basis of meteorological data, while at the end of the period they were clearly "too high". The NDVI index displayed during the 1990s an upward trend (Tab. 4). No significant changes were observed in the period considered in the length nor in the dates of the beginning and end of the growing season, defined on the basis of the thermal criterion (T>5°C). Length of the growing season varied in Łódź between 192 days and 227 days (in 1997 and 1996, respectively), while its beginning varied between the 85th day of the year (1992) and the 106th day (1997).

The increase of the NDVI during 1990s is therefore most probably conditioned by the factors not related to weather, and it is perhaps linked with the change in land use or crop structure.

The growing season (corresponding to persistence of T>5°C) in the 1990s, in spite of the observed temperature increase, especially during winter, but also in the summer (Tab. 5), has not

Tab. 3. Coefficients of the multiple regression equations and correlation coefficients (r) of the 10-day anomalies of the NDVI index with sunshine (S), precipitation (R), and temperature (T) in the four phases of the growing season (phases I through IV, see Tab. 1) for Łódź.

Phase	S	R	T	b	r
I	0.110	– 0.001	– 0.006	0.000	0.40
II	0.003	0.014	0.005	0.000	0.26
III	0.182	0.040	– 0.017	0.000	0.67
IV	0.121	– 0.002	– 0.016	0.000	0.62
I – IV					0.53

Tab. 4. Average differences between the observed and the estimated values of the NDVI (D), the seasonal averages of the $\overline{NDVI}$ value, as well as the beginning (B), end (E) and duration (L_v) of the growing season in Łódź in the years 1992-98

Years	Δ	$\overline{NDVI}$	Growing season		
			B	E	L_v
1992	– 0.045	0.3703	85	300	216
1993	– 0.017	0.3974	89	298	210
1995	0.015	0.4304	87	304	218
1996	0.004	0.4136	94	320	227
1997	0.006	0.4378	106	297	192
1998	0.046	0.4826	86	296	211

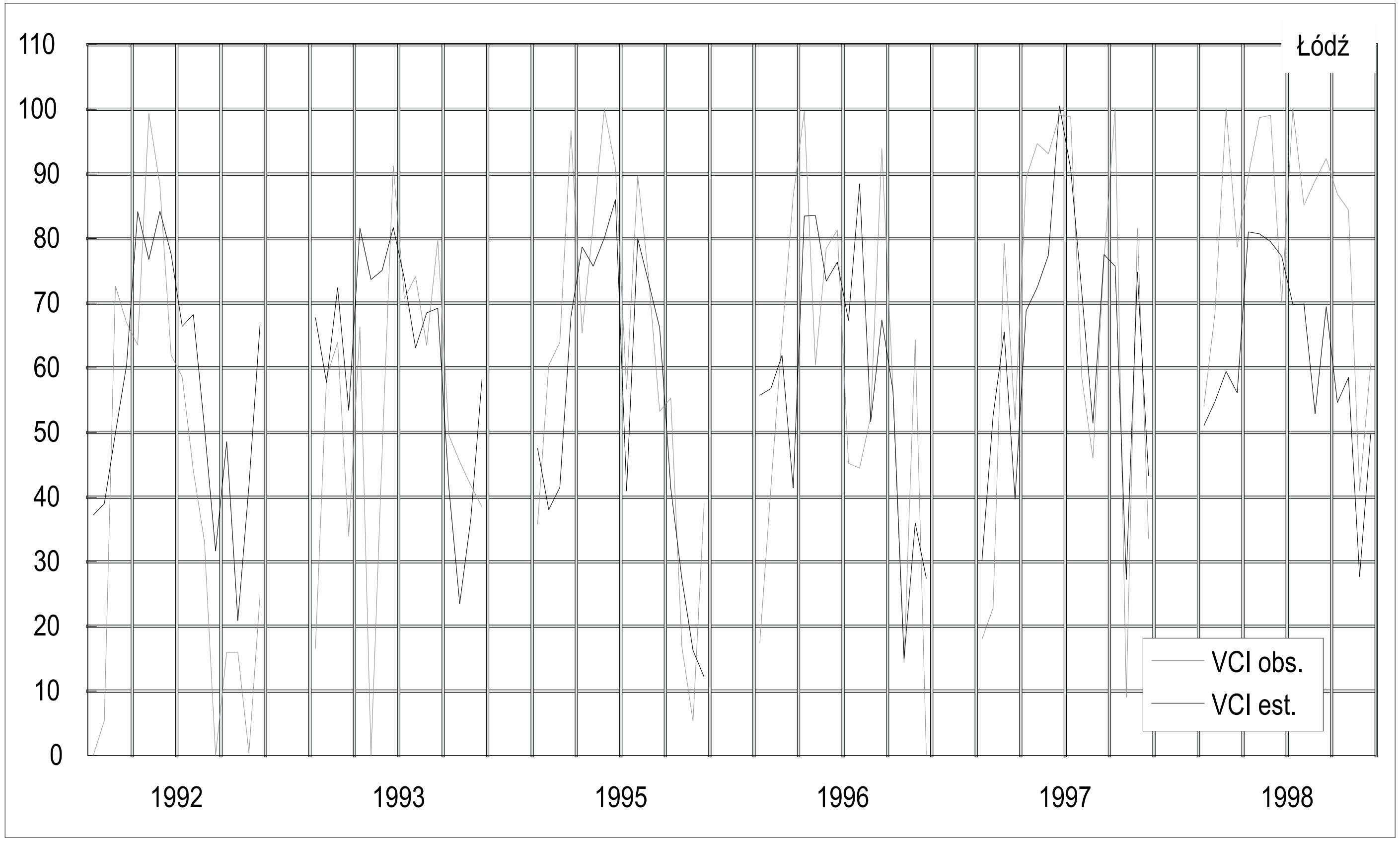

Fig. 2. Observed values of the vegetation condition index (VCI obs.), and its estimated values (VCI est.) in the region of Łódź in the years 1992-98.

Tab. 5. Beginning (B), end (E), and duration (L_v) of the growing season, and the average temperature values for the year (I-XII), winter (XII-II), and summer (VI-VIII) in Poland in the years 1992-98 and 1951-90 (according to the monthly averages from 51 weather stations).

Years	Growing season			$T_{(I-XII)}$	$T_{(XII-II)}$	$T_{(VI-VIII)}$
	B	E	L_v			
1992	85	302	218	8.7	– 0.2	19.2
1993	80	298	219	8.0	– 0.5	15.8
1994	80	308	229	8.8	0.5	18.2
1995	88	304	217	8.1	1.1	18.0
1996	95	321	227	6.5	– 5.0	16.6
1997	105	301	197	7.8	– 2.6	17.5
1998	86	298	213	8.2	1.6	16.9
1992 – 98	88	305	217	8.0	– 0.7	17.5
1951 – 90	90	309	221	7.6	– 1.7	16.8

changed significantly in comparison with its long-term average characteristics from the years 1951-1990. The average duration of the growing season for Poland is, respectively 217 and 221 days (for the corresponding annual average tempera-tures of 8.0°C and 7.6°C, see Tab. 5).

This effect finds a partial explanation in the changes of the annual pattern of temperature, which took place in the 1990s in comparison with the period of 1951–1990 (Fig. 3). As can be seen from the figure, neither winter warming nor the increments of temperature in a part of the warmer season of the year do result in a change in the dates when the threshold of 5°C is crossed.

The length of the growing season with temperature >5°C (L_v) displays a weak correlation with the monthly and seasonal averages of air temperature. Correlation coefficients for L_v are significant – though not too high, neither – only with the average temperatures of these months, during which the threshold of 5°C is being crossed (Tab. 6). In this context one should treat carefully the formulation of the forecasts of an essential extension of the growing season in conditions of the expected climate warming (Demidowicz et al. 1999).

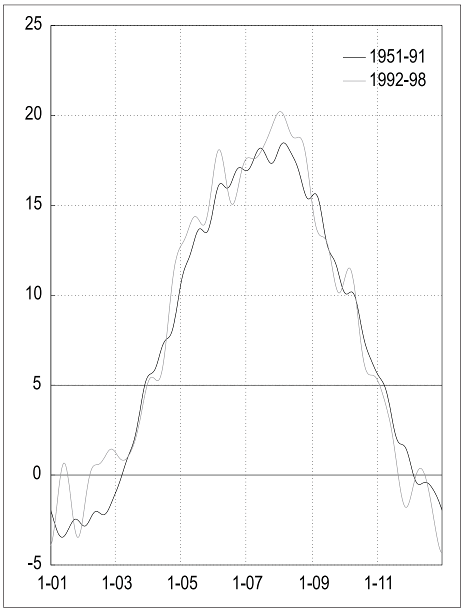

Fig. 3. The average course of air temperature in Łódź in the years 1951-91 and 1992-98. Daily averages smoothed with the polynomial of 10th degree. The threshold of 5°C is indicated.

Tab. 6. Coefficients of correlation (R) of the duration of the growing season (T>5°C) with the average values of temperature in Łódź in the years 1951-98 (^{x} - coefficients significant at the level of 0.05).

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	III-V	VI-VIII	IX-XI	XII-II	I-XII
R	0.21	0.33^{x}	0.53^{x}	0.46^{x}	0.01	0.10	0.11	0.07	-0.03	0.41^{x}	0.54^{x}	-0.26	0.59^{x}	0.14	0.56^{x}	0.31^{x}	0.55^{x}

The major observations, which result from the analyses carried out are as follows:

– synchronous changes of insolation, precipitation, and temperature can explain some 50% of the observed variability of the NDVI index,
– the influence of climatic conditions on the NDVI increases in the second part of the growing season (August – September),
– the length of the growing season has not changed in spite of the increase of the annual average of temperature in the 1990s.

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