

The Variability of Climatic Vegetative Seasons and Thermal Resources at the Polish Baltic Sea Coastline in the Context of Potential Composition of Coastal Forest Communities

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Abstract

This paper examines the variability of climatological vegetative seasons and thermal resources on the Polish Baltic Sea coastline in the second half of the 20th century and the first decade of the 21st century. The annual variability of vegetative seasons and thermal resources determines the composition of forest communities and plays an important role in forest management. The paper identifies periods (seasons) of intensive plant vegetation and flowering; it also presents extreme air temperature values within these periods. The study area covers the Polish Baltic Sea coastline, where weather conditions are recorded at the weather stations: Gdynia, Hel, Leba, Ustka, Kolobrzeg, Dziwnow and Swinoujscie. Average daily air temperatures values taken from the measuring period of 1966–2009 were used in this study. The designation of vegetative seasons was made based on the methodology developed by Makowiec (1983) and thermal resources were identified as described by Niedzwiedz (2003). The results presented allowed to determine the trends in climatic conditions of the Polish coastal area of the Southern Baltic Sea and their potential impact on the composition of coastal forest communities. The variability of vegetative seasons and thermal resources were described for the regions of forest communities within the Polish Baltic Sea coastal area.

Key words: climatological vegetative season, thermal resources, forest communities, the Baltic Sea coastline, thermal extremes

Introduction

The variability of thermal conditions is characterised in a very general manner by the astronomical seasons. From the point of view of forest management, it is necessary to analyse thermal conditions of vegetative periods (seasons) and the thermal resources (effective temperature totals). The length of a vegetative season is a simple agroclimatic indicator used in evaluating the potential of forestry and agriculture, and in the assessment of climate trends (EEA 2012). A vegetative season is the part of an individual year, when vegetation can grow due to a sufficient amount of heat. During vegetative seasons intensive development processes take place. Under moderate climatic conditions, vegetative seasons usually run from the last ground frosts in spring to the first in autumn. The

vegetative season in Poland occurs when the average daily air temperature is higher than 5.0°C, i.e. from the beginning of thermal spring up to the end of thermal autumn. In phenological terms, in Poland it starts from the flowering time of *Corylus avellana*, *Caltha palustris* and *Tussilago farfara* and ends at the falling of *Aesculus hippocastanum* and *Betula pendula* leaves (Molga 1983).

The main purpose of this study was to determine differences in climate change patterns in coastal regions of Poland regarding vegetative seasons and changes in thermal resources on the Polish Southern Baltic coastal area. The paper shows the temporal and spatial variability of vegetative seasons and thermal resources in the main forest communities of coastal regions.

Material and Methods

Material

The specific recognition of thermal climatic features is of major importance for determining the composition of the forest community sea coast zone. The temporal and spatial variability of thermal conditions and thermal resources affects the development of biotic environments including forest communities. The distribution of units and sub-units of deciduous forests along the Polish Baltic Sea coastline depends mainly on their geomorphology, climate and phytodynamics. The Polish Baltic Sea coastline – due to the variability of forest communities – can be divided into 5 regions (Figure 1) (Piotrowska 2003):

– the Western Region. This region with a length of about 40 km covers Wolin Island. Here *Betulo-Quercetum molinietosum* occurs at its Holocene spits and *Betulo-Quercetum deschampsietosum* is present on the island morainic plateau. In the Western Region, cliff seashores dominate with prevailing *Betulo-Quercetum loniceretosum*. There are communities of *Cephalanthero rubrae-Fagetum* and *Luzulo pilosae-Fagetum* with *Solidago virgaurea* at its highest altitude. Abundant floristic beech-wood and birch-oak forests are connected with fertile soils (cliff naspas);

– the Central Region. This is the longest section within the Polish Baltic Sea coastline, which extends over a length of 167 km from Dziwnówek up to Debrina. In the Central Region there are mainly dune seashores and low cliffs that reach a height below 20 m. Only its eastern section – from Ustka up to Debrina – is characterised by higher cliff seashores. In low areas of the sea coastline the following communities occur: *Pruno-Fraxinetum sambucetosum* or *Pruno-Fraxinetum coryletosum* and *Betulo-Quercetum prunetosum* plus *Betulo-Quercetum typicum*. *Betulo-Quercetum deschampsietosum* occurs on hills. Above the cliffs there is *Luzulo pilosae-Fagetum typicum* and its enriched form *Solidago virgaurea*;

– the Eastern Region. The length of this region is 70 km. It occurs at the dune dominated coastline of the Leba Spit and the region is distinguished by the occurrence of communities of thick forests. Coastal thick pine forests (*Empetro nigri-Pinetum*) form the dominant forest communities (Wojterski 1964). The Eastern Region forms a gap in the distribution of mesophilic forests along the coastline;

– the Kashubian Coastland. This is the most diverse (in geomorphological and phytocenotical terms) section of the Polish Baltic Sea coastline. *Betulo-Quercetum convallarietosum* occurs within small areas in the proximity of Dabki. *Betulo-Quercetum typicum*, *Betulo-Quercetum prunetosum* and *Betulo-Quercetum molinietosum* are present on fossil turf soils covered with sand. There is old fertile beech-wood (*Galio odorati-Fagetum*) at the cliffs in the proximity of Rozewie;

– the Vistula Spit. *Betulo-Quercetum deschampsietosum* with planted *Pinus* stands are present here; however, there are no phytocenoses of *Pruno-Fraxinetum* and more fertile sub-units of *Betulo-Quercetum*. The Vistula Spit section was not characterised in terms of its vegetative seasons as no long-term meteorological measurements were taken in the area.

The data sources used to determine vegetative seasons and thermal resources along the Polish Baltic Sea coastline were average daily air temperatures for the period of 1966–2009 from seven coastal meteorological stations as follows: Gdynia, Hel, Żłeba, Ustka, Kolobrzeg, Dziwnów and Swinoujście. The series of measurements used in the study ensure the comparability and reliability of observed trends. The above data were obtained from the Institute of Meteorology and Water Management in Warsaw.

Methods

Various methods for determining the start dates of thermal seasons and their related vegetative times were applied in the climatic studies. Thermal seasons

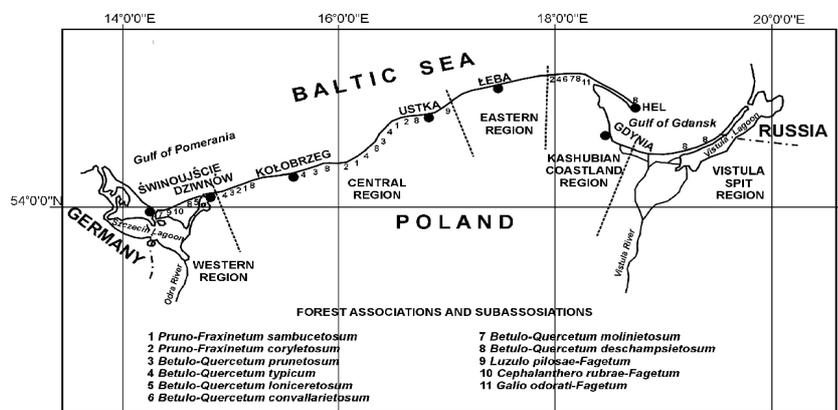


Figure 1. Area covered by the study – the location of meteorological stations in the main forest communities of the Polish Baltic Sea coastline

are predominantly determined on the grounds of average monthly or daily air temperatures (Jones and Briffa 1995, Szyga-Pluta 2011, Wiszniewski 1960). The methodology for determining the vegetative seasons is included, among others, in the work of Makowiec (1983), Molga (1983) and Piotrowicz (2000). The determination of vegetative seasons should consider the features of moderate transitional climatic conditions in Poland. In Poland the climate has both the characteristics of sea moderate climatic conditions that occur in the Western Europe and the characteristics of continental moderate climatic conditions that are typical for the Eastern Europe.

Start and end dates of vegetative seasons were determined on the basis of average daily air temperature values. Their duration in individual years was estimated by the periods of sustained average daily air temperatures above 5.0°C. Frequent crossing of the threshold value by average daily air temperatures was a major impediment to determining start and end dates of vegetative seasons. The methodology used for specific determination of start and end dates of vegetative seasons was taken from the studies by Huculak and Makowiec (1977) and Makowiec (1983). The start dates of vegetative seasons were set based on the earliest day (within an individual year) with average daily air temperature exceeding 5.0°C, which start cumulative deviations of average daily air temperatures from the threshold value of 5.0°C and do not reach below-zero temperatures until the end of the year. Then, end dates of vegetative seasons are set based on the earliest day (within an individual year) with average daily air temperatures at least 5.0°C, which start cumulative deviations of average daily air temperatures from the threshold value of 5.0°C that fall below 0°C and do not reach zero or above-zero temperatures until the end of the year. Thus, the thermal threshold >5.0°C determines the start of vegetative seasons. A threshold temperature of 10.0°C indicates the intensive vegetative periods (flowering period); a threshold value >15.0°C marks the start of the ripening periods (Huculak and Makowiec 1977, Makowiec 1983). A threshold value of average daily air temperatures of at least of 2.5°C is considered to be the start of agricultural and forestry work. The threshold temperatures are relevant for the development of vegetation and forest management. Vegetative season durations – the start and end dates for all the years within the long-term period under consideration – were identified in the study. A range of fluctuations of start and end dates of vegetative seasons and their potential length (i.e. the period between the date of the earliest start and the date of the latest end of vegetative seasons within the period under consideration) were also

indicated. In addition, the characteristics of vegetative seasons and extreme annual and daily air temperatures were also considered.

An agro-climatic indicator was used to determine the variability of thermal resources in Polish Baltic coastline forest community regions. The agroforest-climatic indicator measures effective temperature totals, i.e. the aggregates of positive variations of average daily air temperatures from the threshold value, which represents the biological minimum of plants at their phenological stage (Niedzwiedz 2003). The temperature totals exceeding the thermal threshold were adopted at the biological minimum (the so-called physiological zero 5.0°C). The thermal resources calculated in this manner (which means the surplus totals of average daily air temperatures above the threshold of 5.0°C) reflect the optimal measurement of their vegetative rates (Zmudzka 2012).

A non-parametric analysis of statistical significance trends of the Polish Baltic coastal zone was made using the Mann-Kendall test (Mitchell 1966): average annual air temperature, length of vegetative season and the amount of thermal resources.

The Pearson correlation analysis was performed to test relationships between the mean annual air temperature and the length of the thermal seasons: vegetative, flowering and ripening.

Results

The average annual air temperature in the Polish Baltic coastal region was 8.3°C in 1966–2009 and it was found to decrease towards the Polish Baltic Sea eastern coastline. In the Western Region, the average annual air temperature was 8.6°C both in Swinoujście and Dziwnów, and it was considerably lower in the Central Region, with 8.3°C in Kolobrzeg and 8.2°C in Ustka. The coldest area of the coastline was the region of open sea in the Eastern Region, where the average annual air temperature in Leba was 7.9°C. Within the Kashubian Coastland Region situated in the warmer area of Gdansk Bay, the average annual air temperature was 8.2°C in Hel and 8.5°C near Gdynia. The absolutely lowest average annual air temperature of 6.4°C was recorded in Hel in 1987, and the absolutely highest average annual air temperature of 10.0°C was observed in Dziwnów and Gdynia in 1990. The amplitude of the extreme daily air temperatures at the Polish Baltic Sea coastline was 61.2°C. The lowest daily air temperature of -23.2°C was recorded on 6 January 2003 in Leba, and the highest daily air temperature of 38.0°C was observed on 10 August 1992 in Kolobrzeg.

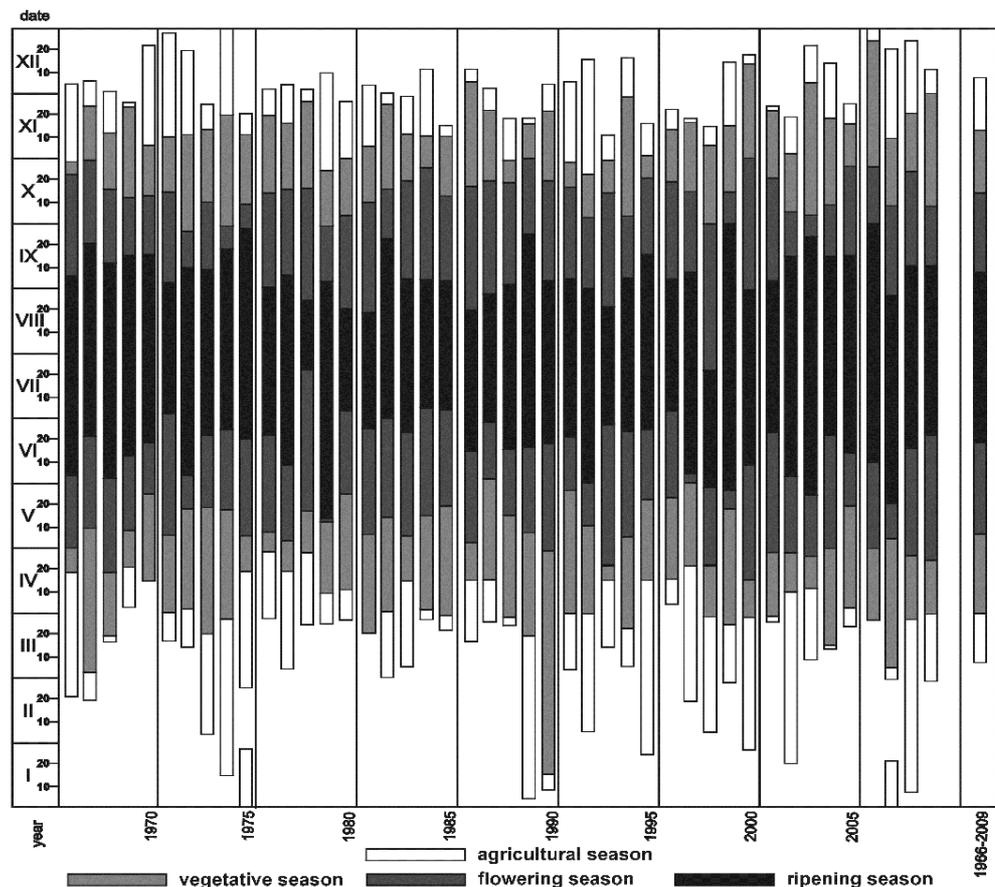
The analysis of average daily air temperatures from seven coastal meteorological stations showed that on

average the vegetative season lasts for 226 days per year. On the Polish Baltic Sea coastline, on average it starts on 1 April and ends on 12 November. The flowering period lasts for 159 days, on average from 8 May up to 13 October. Then, the ripening period lasts for 82 days, on average from 19 June up to 8 September. The forestry work season on the Polish Southern Baltic Sea coastline can be performed on average for 275 days per year, within the period from 8 March up to 7 December (Figure 2).

The variability in the duration of vegetative seasons for the whole Polish Baltic Sea coastal area ranged from 194 days in 1966 up to 310 days in 1990. The length of vegetative seasons in individual years corresponded to average annual air temperatures indicated by a high correlation coefficient of 0.6. Vegetative seasons started on 16 January 1990 at the earliest and on 30 April 1976 at the latest. They ended on 22 October 1992 at the earliest and in 2006 at the latest when an average daily air temperature of >5°C remained until 24 December (Figure 2). The potential duration of a vegetative season on the Polish Baltic Sea coastal area (which means the period from the date of the earliest start up to the date of the latest end) can be from 308

days in Eastern Region and Kashubian Coastland to 344 days in Central and Western Regions. Within vegetative seasons, the flowering period started on 17 April 2000 at the earliest and on 3 June 1987 at the latest. The variability of end dates of flowering periods ranged from 26 September 1972 up to 31 October 2000. The longest flowering season of 198 days occurred in 2000 and the shortest with just 131 days took place in 1972. The potential duration of a flowering season is equal to 198 days. The variability in duration of ripening seasons was very high and ranged from 33 days in 1978 up to 126 days in 1999. Their extreme start dates were 15 May in 1979 and 23 July in 1978. Their end dates ranged from 18 August in 1981 up to 30 September in 1999. The potential duration of a ripening season was 139 days. The standard deviation (σ) of the duration of vegetative seasons was 24 days. The start date was more variable (standard deviation of 18 days) than the end dates (standard deviation of 2 weeks). Variability was higher for the duration of ripening season ($\sigma = 19$ days) than for flowering season ($\sigma = 15$ days). The duration of season of forestry works ranged from 232 days in 1996 up to 351 days in 2008. Forestry work was possible to be

Figure 2. Vegetative, flowering and ripening seasons, as well as the agricultural and forestry work season, at the Polish coastline of the Baltic Sea in the period of 1966–2009



gin in 1989 at the earliest (from 5 January) and in 1970 at the latest (from 17 April). The respective extreme end dates were 10 November (in 1973) and 27 January (in 1975) (Figure 2).

The average duration of a vegetative season increases towards the Polish Baltic Sea western coast-line. In the Western Region, in Swinoujscie, the vegetative seasons last for an average of 235 days, from 20 March to 16 November. The Eastern Region has the shortest vegetative season of 217 days on average, from 3 April to 13 November. The longest vegetative season of 310 days was recorded in 1992 along the Baltic Sea western coastline from Swinoujscie to Kolobrzeg. The shortest vegetative season was reported in the Eastern Region in 1992 and extended for 176 days and. Vegetative seasons at the Polish Baltic Sea coastline started on 16 January at the earliest and end on 25 December at the latest. The potential duration of a vegetative season was 308 days in the Kashubian Coastland and Eastern Regions up to more than 340 days in the Central and Western Regions (Table 1).

A statistically significant half-normal distribution of the vegetation season durations was observed for the meteorological stations that were analysed. The standard deviation of their length had similar values and ranged from 20 days in Hel up to 24 days in Kolobrzeg. The largest annual variability in duration was reported for Leba (variation coefficient 10.8%) and the smallest for Gdynia (variation coefficient 9.1%). The

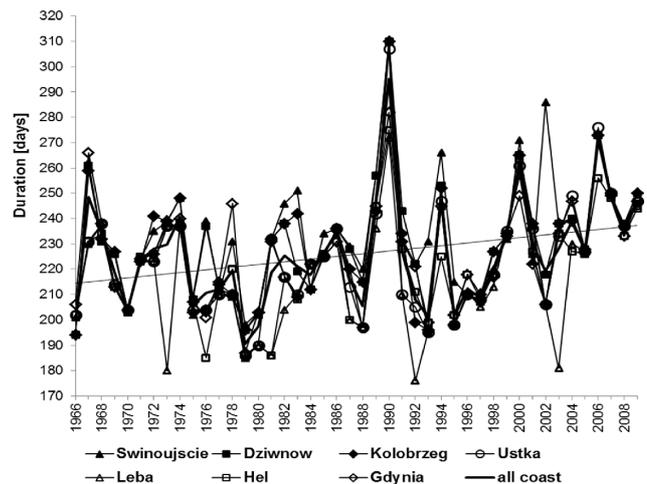


Figure 3. Statistical characteristics of vegetative season durations within the Polish coastal area of the Baltic Sea in 1966–2009

cant coefficient of average air temperature linear trends (Mann-Kendall test) for the entire coast was 0.32°C per 10 years. The highest increase in air temperatures (0.33°C per 10 years) was observed in the Western Region, and the lowest increase in average annual air temperature (0.29°C per 10 years) in the eastern part of the Polish Baltic Sea coastline within the Kashubian Coastland Region. For the Southern Baltic coastline, a strikingly colder period occurred from 1966 up to 1988. From 1989 up to 2009, a significant warming

Table 1. Characteristics of vegetative seasons within the Polish coastal area of the Baltic Sea in 1966–2009

Forest communities region	Meteorological station	Beginning date			Ending date			Duration [days]			Potential duration [days]
		Min	Average	Max	Min	Average	Max	Min	Average	Max	
Western	Swinoujscie	16 I	20 III	19 IV	23 X	16 XI	24 XII	195	235	310	343
	Dziwnow	16 I	31 III	30 IV	22 X	17 XI	24 XII	194	230	310	343
Central	Kolobrzeg	16 I	20 III	30 IV	16 X	16 XI	24 XII	194	229	310	343
	Ustka	16 I	1 IV	30 IV	22 X	18 XI	27 XII	186	224	307	346
Eastern	Leba	20 II	3 IV	4 V	12 X	13 XI	24 XII	176	217	273	308
Kashubian Coastland	Hel	20 II	3 IV	4 V	14 X	16 XI	24 XII	185	221	275	308
	Gdynia	20 II	31 III	25 IV	14 X	16 XI	25 XII	187	226	282	309

distribution of the annual season duration has a slight right-sided asymmetry (positive coefficient of skewness), while a positive kurtosis was observed for the vast majority of cases (apart from Leba) indicating close concentration around the average value. The duration of vegetative season was shorter closer to the Polish Baltic Sea eastern coastline, indicated by lower average values and, in particular, their maximal and minimal durations (Figure 3).

The thermal analysis of the Polish Baltic Sea coastal area for the period of 1966–2009 showed an increasing trend in average annual air temperatures (Table 2). The standard deviation of average annual air temperatures within the studied period for all the stations analysed was 0.8°C. The statistically signifi-

was observed (a particularly warm period took place in the first decade of the 21st century), (Tylkowski 2013). The increasing trends of air temperatures are similar to the results presented in other publications, for example in Ustka for the period of 1951–2005, with a linear trend coefficient 0.26°C per 10 years (Michalska 2011).

The increasing trend in average annual air temperatures in 1966–2009 is related to the duration of vegetative seasons, which is confirmed by a statistically significant Pearson’s correlation coefficient of 0.67 (Figure 4).

The statistically significant coefficient of vegetation season duration linear trends (Mann–Kendall trend test) for the entire coast was +5.5 days per 10

Table 2. Increase trend in annual air temperature at the Polish Baltic coastal area in 1966–2009 (Mann-Kendall trend test)

Parameter	Swinoujscie	Dziwnow	Kolobrzeg	Ustka	Leba	Hel	Gdynia	All coast
Kendall's tau	0.387	0.368	0.372	0.374	0.404	0.376	0.376	0.370
p-value	0.0002	0.0004	0.0004	0.0004	0.0001	0.0003	0.0003	0.0004
alpha	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Increase trend of air temperature [°C] per 10 years	0.32	0.34	0.32	0.33	0.32	0.30	0.29	0.32

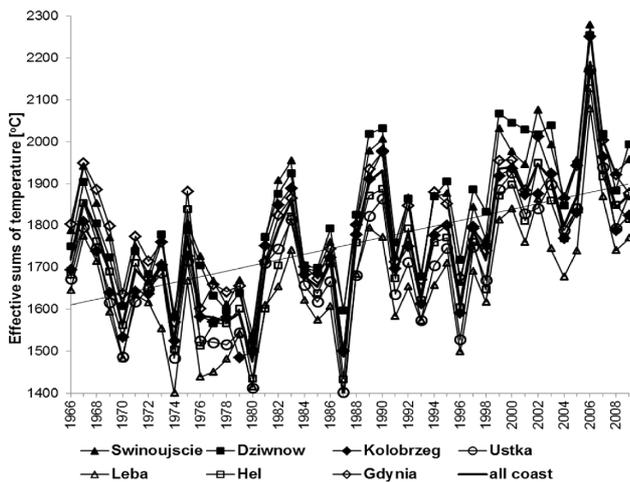


Figure 4. Pearson's correlation between annual average air temperature and duration of vegetative season in the Polish Baltic coastal areas in 1966–2009

years. The most extended vegetation season was in the Central Region in Ustka, which had a positive trend of +6.1 days per 10 years. In the Western Region there was a positive trend of +5.4 days per 10 years. In Swinoujscie the duration increases +5.9 days per 10 years. In Dziwnow, the trend is slightly lower (+4.8 days per 10 years). The least increase in vegetation duration was found for the Kashubian Coastland Region in Hel and the Eastern Region in Leba. In these regions, the duration of vegetation increased +5.2 days per 10 years. In Kolobrzeg and Gdynia, the increasing trend in vegetation duration was not statistically significant (Table 3).

The Polish Baltic Sea coastline is characterised by a minor range of changes of effective temperature totals in vegetative seasons, which ranged from 698°C in the Eastern Region (Leba) up to 734°C in the Western Region (Swinoujscie and Dziwnow). The highest

average annual effective air temperature total was found in the Western Region (Swinoujscie 1823°C and Dziwnow 1827°C) and the Kashubian Coastland Region (Hel 1730°C and Gdynia 1804°C), while the lowest thermal surplus total in the Eastern Region (Leba 1653°C). In terms of their temporal variability, exceptionally minor surplus totals of average daily air temperatures above 5.0°C (the threshold) were recorded during the 1960s, at the turn of the 1970s to 1980s and in 1987. Extremely large effective temperature totals were observed at the beginning of the 21st century, especially in 2006 (Table 4).

Table 4. Basic characteristics of the distribution of effective temperature totals (°C) above 5.0°C (the threshold) at the coastal meteorological stations in Poland within 1966–2009

Meteorological station	Forest communities region	Statistical properties				
		Average	Mediana	Maximum (year)	Minimum (year)	Standard deviation
Swinoujscie	Western	1823	1805	2279 (2006)	1542 (1980)	153
Dziwnow		1827	1815	2255 (2006)	1524 (1980)	160
Kolobrzeg	Central	1745	1752	2167 (2006)	1485 (1979)	147
Ustka		1706	1708	2171 (2006)	1402 (1987)	154
Leba	Eastern	1652	1653	2078 (2006)	1381 (1987)	140
Hel	Kashubian Coastland	1730	1735	2127 (2006)	1434 (1987)	142
Gdynia		1804	1803	2252 (2006)	1499 (1987)	148
	all coast	1755	1751	2279 (2006)	1381 (1987)	161

Along the Polish Baltic Sea coastline, a statistically significant upward trend of +6.0°C in effective temperature totals in the course of training seasons was observed (Table 5). Thermal resources increased most rapidly in the Western Region with a recorded positive trend of +7.5°C per 1 year. In Swinoujscie, the annual rate of thermal resource increase was +7.0°C, and in Dziwnow +8.0°C. Its lowest rate was recorded in the Kashubian Coastland Region with a recorded annual level of +5.7°C. Within the Kashubian Coastland Region the lowest increase in thermal resources occurred in Gdynia at +5.5°C per 1 year. In Hel, the trend was slightly higher and equal to 5.9°C per 1 year.

Table 3. Increase trend in vegetation season duration at the Polish Baltic coastal area in 1966–2009 (Mann-Kendall trend test)

Parameter	Swinoujscie	Dziwnow	Kolobrzeg	Ustka	Leba	Hel	Gdynia	All coast
Kendall's tau	0.214	0.241	0.188	0.241	0.214	0.246	0.200	0.257
p-value	0.043	0.023	0.075	0.023	0.042	0.020	0.058	0.014
alpha	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Increase trend of vegetation season duration [days] per 10 years	5.9	4.8		6.1	5.5	5.2		5.5

In the Central and Eastern Regions, intermediate increase values were recorded. In the Central Region the annual value was +6.8°C (it reached a level of +6.6°C in Kolobrzeg and +7.0°C in Ustka). In the Eastern Region, an increasing rate of thermal resources at the level of +5.9°C per 1 year was reported.

and Fabian 1999), -2.8 days/10 years (Chmielewski and Rotzer 2001, 2002), -5.8 days/10 years (Ahas et al. 2002). Later end dates of vegetative seasons at the Polish Baltic Sea coastline show a slightly more warming trend compared to e.g. Spain: 2.7 days/10 years (Penuelas et al. 2002), Germany: 2.7 days/10 years

Table 5. Increase trend in effective temperature totals during vegetative seasons at the Polish Baltic coastal area in 1966–2009 (Mann-Kendall trend test)

Parameter	Swinoujscie	Dziwnow	Kolobrzeg	Ustka	Leba	Hel	Gdynia	All coast
Kendall's tau	0.389	0.429	0.416	0.431	0.381	0.381	0.338	0.421
p-value	0.0002	0.0001	0.0001	0.0001	0.0003	0.0003	0.0012	0.0001
alpha	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Increase trend of effective temperature totals during vegetative seasons [°C] per 1 years	5.9	8.0	6.6	7.0	5.9	5.9	5.5	6.6

Correlation analysis between thermal resources and duration of vegetative seasons and annual average temperature showed statistically significant relationships (Figure 5). A higher correlation between annual thermal resources and the average annual air temperature ($r = 0.83$) than the duration of the vegetation season ($r = 0.39$) was observed.

(Menzel et al. 2003) and the North-Eastern Europe: 0.3 days/10 years (Linderholm et al. 2008). The duration of vegetative seasons (+5.4 days/10 years) at the Baltic Sea coastline in Poland shows a similar increasing trend compared to that in the Western Europe, e.g. Spain: 6.0 days/10 years (Penuelas et al. 2002), Germany: +4.9 days/10 years (Menzel et al. 2003), and Aus-

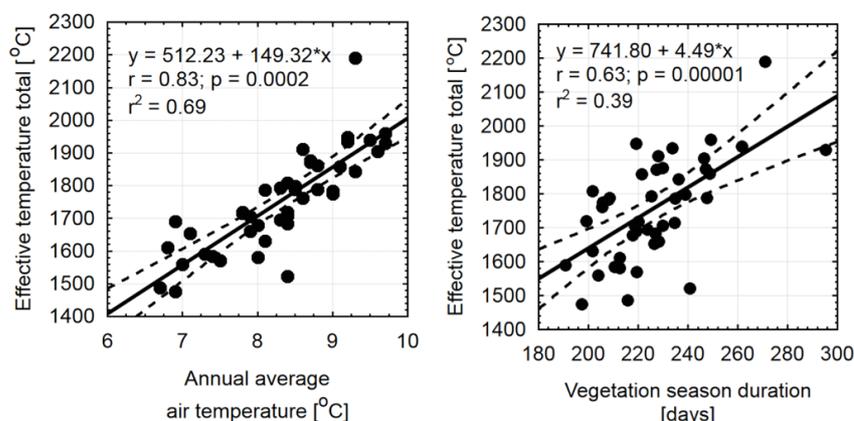


Figure 5. The Pearson's correlation between thermal resources (total of effective temperatures) and annual average air temperature and duration of vegetative season at the Polish Baltic coast in 1966–2009

Discussion and Conclusions

Studies of the vegetation season have become an important scientific issue for research into global climate change (Carter 1998, Linderholm 2006). The ten-year trend in start dates (-2.3 days) and end dates (+3.1 days) of vegetative seasons at the Polish Baltic Sea coastline in 1966–2009 is similar to the results recorded in other climatic studies in Europe. Earlier start dates of vegetative seasons in the coastal region in Poland are very similar to the trends observed in e.g. the Greater Baltic Area: -1.3 days/10 years (Linderholm et al. 2008), the UK: -2.7 days/10 years (Fitter and Fitter 2002), Germany: -2.3 days/10 years (Chmielewski et al. 2004) and Europe: -1.4 days/10 years (Menzel

tria: 3.7 days/10 years (Hasenauer et al. 1999). Climatological vegetative seasons at the southern coastline of the Baltic Sea in Poland are much longer than those in the north-eastern Europe 1.5 days/10 years (Linderholm et al. 2008).

The Baltic Sea coastline and North-Western regions are characterized by the greatest thermal changes in Poland (Degirmendzic and Kozuchowski 2005, Kozminski 2009, Niedzwiedz and Limanowka 1992, Nierobca et al. 2013). The characteristic features of thermal conditions related with increased air temperatures along the Polish Baltic Sea coastline in 1966–2009 were the following: extended vegetative seasons (at a rate of ~0.5 days per year) and increased thermal resources in vegetative periods (at a rate of ~6°C per year).

The upward trends on durations of vegetative seasons in the coastal regions of forest communities along the Polish Baltic Sea coastline declined eastwards. These extended vegetative seasons and increased thermal resources in the coastal regions of forest communities were spatially differentiated. There was a particularly intensive increase in the duration of vegetative seasons and thermal resources reported for the Western Region, which has the most favourable conditions in forest-climatic terms. The lowest rate of changes in thermal conditions was observed in the eastern part of the Polish Baltic Sea coastline within the Kashubian Coastland Region. For the whole coast, an increase in the duration of vegetative seasons at +5.4 days per 10 years was observed. Within the coastal area, effective temperature totals above 5.0°C (the threshold) increased at a rate of 59°C per 10 years. These results were similar with the results of studies by other authors, who estimated changes in the durations and start and end dates of selected thermal periods in Poland, for example Fortuniak et al. (2001), Gorski (2006) and Kozminski (2009).

The upward trend in the average annual air temperatures, longer vegetative seasons and greater thermal resources may affect transformations of phytocenoses in the Baltic Sea Region (Ahas et al. 2000, Juknys et al. 2012, Romanovskaja and Baksiene 2006, Shutova et al. 2006, Trnka et al. 2011, Veriankaite et al. 2010). A long favourable increasing trend in thermal resources in the Polish Baltic Sea coastal regions may cause transformations of forest areas and facilitate invasion of species that have greater thermal requirements. The tetratherm of Mayr (1906) at the Baltic Sea coastline is 15.2°C. Coastal forests provide a zone of transition between *Piceetum* forests with low thermal requirements (the favorable tetratherm of the average air temperature from May to August 10 is 14°C) and *Fagetum* areas with higher thermal requirements (tetratherm 16–18°C). Given the current rate of increase in the average air temperature (0.32°C/10 years), in about 20 years the entire Polish Baltic Sea coastline will offer potentially very favourable conditions for the development of *Fagetum* forests. In about 150 years, the Baltic Sea coastline in Poland might as well feature the warmest *Castanetum* forests in Central Europe. Greater thermal resources would result in the gradual disappearance of less demanding tree species (*Betula*, *Pinus*) and lead to the development of those with greater thermal requirements (*Fagus*, *Quercus*). The mild climate at the Baltic Sea coastline is conducive to the introduction of both native tree species, such as *Picea abies*, *Abies alba*, and alien tree species, such as *Picea sitchensis*, *Abies grandis*, into the coastline regions (Feliksik and Wilczynski

2009). Potential transformations of forest areas and communities at the Polish Baltic Sea coastline would be most expected in the Western Region, characterised by the largest change in thermal conditions (tetratherm 15.5°C, ten-year upward trend in thermal resources 75°C), then in the Eastern Region (tetratherm 14.7°C, ten-year upward trend in thermal resources 59°C) and later in the Vistula Spit.

The extended climatological vegetative seasons and increased thermal resources have important implications for plant vegetation and production, as they may lead to:

- earlier sowing of plants and earlier start of forestry work,
- introduction of plants with higher thermal requirements into forestry management and reduction in the risks of cultivation of thermophilic plants,
- introduction of new varieties of plants and promotion of species diversity.

The reported changes of thermal conditions may also have adverse effects for forestry through:

- reduced productivity of some forestry plantings as a result of heat stress and degraded water balance,
- intensified development of thermophilic plants, pests or the occurrence of new plant diseases,
- harmful introduction of invasive species into natural forest communities.

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