Phenological Response of Airborne *Alnus* Mill Pollen to Climatic Conditions in Turkey and Global Climatic Changes

Hatice Kutluk
Department of Geology (Paleobotany)
Eskişehir Osmangazi University
26480 Batı Meselik
Eskişehir
Turkey

Abstract

A total of 9914 airborne Alnus glutinosa pollen which belong to a two-year period in the İstanbul area indicated a strong positive relationship with air temperature, rainfall and wind velocity; and an inverse relationship to relative humidity. Analysis of the climatic variables of the study area and the nearby meteorological stations of the last fourty years has shown that a 0,3-0,6°C increase in average annual temperature and 12-19 % increase in annual precipitation have occurred consistent with global climatic change. The results have shown that the onset of pollen dissemination of Alder is within the tolerable limits at the present however, future projections reveal that earlier timing of flowering may happen within 3 to 10 years of period with ongoing changes in climate.

Keywords: Airborne *Alnus* pollen, Phenology, Climate Change, İstanbul, Turkey

1. Introduction

Environmental conditions play an important role in the behaviour of plants and influence species distribution. Spatial changes in the distribution of the plants become inevitable if changes in climatic factors in a region are beyond the tolerance of species' physiological thresholds. Recent studies (Parmesan and Yohe, 2003; Root et al., 2003; Walther et al., 2002; Lenoir et al., 2008; Chen et al., 2011; Thuiller et al 2008) show that some species have already altered their distribution latitidunally to more poleward regions or altitidunally to upslope areas as a response to increasing global temperature. Industrialization has increased atmospheric CO_2 concentrations which resulted in increase in temperatures and in altering precipitation regimes. During the last century the Earth has warmed by approximately 0,7 ^{o}C and the temperature is expected to rise more rapidly in the next hundred years by 1,4 - 5,8 ^{o}C (IPCC, 2007). Increasing evidence reveals that human-induced environmental changes pose severe threats for biodiversity and ecosystems. Some species face extinction or have become extinct already as a consequence of recent climatic changes (Parmesan and Yaho, 2003; Parmesan, 2006). Predictions of the species' response to future changes are diffucult to ascertain; a close monitoring of recent changes and long term data sets of the past are required to interpret the responses and for making accurate future projections.

The timing of phenological events is known to be related to environmental variables mostly to temperature and precipitation (Menzel and Fabian, 1999; Perez et al.,2003; Peternel et al., 2005). The phenological characteristics of an environmentally sensitive species *Alnus glutinosa* from the İstanbul region is investigated in this study. The relationship of the airborne *Alnus* pollen to climatic factors; temperature, humidity, rainfall and wind speed is analyzed to test the effect of climatic variables on phenology. The data set belonged to two consecutive years, 1968 and 1969 in which annual and hourly counts of airborne *Alnus* pollen and hourly and diurnal measures of climatic variables are known.

The results of the accumulated temperature requirement of *Alnus* of this time period are also compared with the findings of different time intervals of the same region and with the areas of different climatic settings in Turkey. One of the data sets compared, covered a ten years of period from 1944 to 1954 from the same area (Kayacık, 1957). The other is from the Trabzon area, in the Eastern Black Sea region covering a five-years of period from 1981 to1985 (Küçük, 1986). The recent data set is from different climatic settings covering the years from 1995-2002 with a duration of at least one to at most three years of period. The locations are Balıkesir, Bartın, Bursa, Denizli and Zonguldak.

The effect of accumulated temperature on the onset of flowering time of *Alnus* in this manner, is inferred from the comparison of different time intervals of '1944-1954', '1981-1985' and '1995-2002' with that of '1968-1969'. Over the past 100 years, the Earth's climate has witnessed two main periods of warming, between 1910 and 1945 and from 1976 onwards (Fig. 1). The rate of warming during the latter period has been approximately double of the first and greater than at any other time during the last 1,000 years (Walther et al., 2002). The data sets of 1968-1969 and 1944-1954 from the İstanbul region are coincident with cool period between the two warming trends. The interval 1981-1985 belongs to the beginning stage and the recent data from 1995 to 2002 interval is in the second phase of the warming trend (Fig. 1). Overall data starting from the year 1944 and ending in 2002 spanning a time period of nearly 60 years is adequate to interpret and infer the response of *Alnus* species to long term climatic changes.

The genus *Alnus* is widely distributed in the temperate and cool regions of the Northern Hemisphere. Among its *ca.* 30 species, *Alnus glutinosa* finds its optimum conditions in northern and central Europe (Browicz 1987, Kajba and Gracan 2008) (Fig. 2). The countries in the Northern Mediterranean, Spain, Italy, Greece and Turkey, are the areas delimiting its southernmost occurence. It is also scatteringly recorded in North Africa and the Middle East. Within its distribution covering a wide area from Europe-to Asia-to Africa, Turkey is the place where the species is most diversified at infraspecific level owing to the variations in climate. *Alnus* is ecologically known as a sensitive taxon to climatic changes. Because of having fast rate of growth and tolerating poor soils it is regarded as a pioneer genus for re-establishing woodlands and land reclamation sites. Fossil pollen studies reveal that the genus having seedlings intolerant of shade, rapidly expanded from their sheltered habitats and colonized in open areas following climatic ameliorations and therefore is also regarded as a pioneer genus for playing a key role in detecting climatic changes in the geological past.

2. Materials-Methods

2.1. The Study Site

Airborne pollen of *Alnus glutinosa* was collected from the Belgrade Forest which covers an area of ca. 5060 ha., in Bahçeköy (28° 59'E - 41° 10'N), 20 km north of İstanbul (Fig. 3) by a Hirst volumetric trap and hourly counts of pollen per volume of air (10 lt/hr.) were determined (Aytuğ et al., 1974). Overall pollen flora of the forest has been investigated by Kutluk and Aytuğ (2001; 2010) and a 641,553 pollen grains were counted; a total of 9914 of these belonged to *Alnus*. The quantity of airborne pollen depends on the factors, such as genetic potential of each plant species, falling velocity of pollen, height of trees, woodland density, limitations in dispersal, etc. and consequently pollen in the air becomes over-, equally-, or under-represented than the plant in the vegetation. Comparison of the amount of overall pollen with the suroundıng vegetation in the study area revealed that *Alnus* pollen is represented by a ratio of 4.8 % within the arboreal assemblage and 2.7 % in the overall pollen flora. The studies carried out in the Netherlands and Italy induced Spieksma et al. (1989) that the ratio of atmospheric *Alnus* pollen ranging from 4,7 to 9,3 % was 'equally represented' whereas a ratio of 0,5 % was 'under-represented'. The ratio (4,8 %) of anemophilous *Alnus* pollen in this study therefore, is regarded as 'equally' represent the vegetation.

Of 9,914 of the *Alnus* pollen, 3,515 were recorded in the first and 6,399 in the second year (Table 1; Appendix 1). The 'entire' periods of pollen production of *Alnus* were from February to June, lasting 118 and 143 days in the first and second years respectively (first year: March 3-June 28; second year: February 9-June 30). The 'maximum dissemination' with a total of 9,798 pollen grains, occurred during February-April, lasting 33 and 56 days (first year: March 4-April 5; second year: February 15-March 25). The amount of pollen, temperature, relative humidity, precipitation and wind speed are given in Table 1, Appendix 1 and illustrated in Figs. 4 and 5 during the 'entire' and 'maximum dissemination' periods. The sites of different climating settings and the airborne pollen data from the various growing sites of Alder in Turkey spanning the time periods of '1944-1954', '1981-1985' and '1995-2002' are summarized in Table 2 and the relevant climatic information is given in Figs. 7 A-C.

3. Results

3.1. Relationship between the amount of pollen and temperature, rainfall, relative humidity and wind speed

3.1.1. Temperature during the Dissemination Period

The maximum dissemination of *Alnus glutinosa* pollen, with a total of 3,451 and 6,347 grains, occurred between March 4-April 5 and February 15-April 10, with three and four peak levels in the first and second years respectively (Fig. 4, Table 1). All peak levels were concurrent the rising air temperatures, i.e. reductions in the amount of pollen occurred with decrease in temperature. The results reached on the daily basis when tested by regression analysis on an hourly basis also revealed positive relationship between the pollen output and the temperature. The regression [where y is the dependent (amount of pollen) and x is the independent (temperature) variables] between the hourly temperatures and the amount of pollen yielded a positive relationship with an equation of : y = 0,5178 x + 1,4528; with a positive correlation coefficient of R^2 of 0,0232 for the year 1968; and y = 0,6657 x – 0,188; with a positive correlation coefficient of R^2 of 0,0573 for the year 1969 confirming the results of a positive relationship between the pollen output and the temperature (Fig. 6).

3.1.2. Rainfall and Pollen Dissemination

A sudden drop in pollen amount occurred just after the most heavy rainfall (6-7 mm/day) of the maximum dissemination period in the first year in the study area (Fig. 4). In the second year, similar drops also occurred after the rainfalls on the 25th of March (4 mm/day) and the 2nd of April (3.8 mm/day). The results obtained from both years indicate that the release of pollen from the plant increases after rainfalls.

3.1.3. Relative Humidity and Pollen Dissemination

Relative humidity changed from a minimum of 40 to a maximum of 98,2 % in the year 1968 and from 55,1 to 97,3 % in the year 1969 in the study area (Fig. 4). The results of the regression analysis indicated a negative relationship between relative humidity and the amount of pollen indicating that the dispersion of arboreal pollen requires low relative humidity. The regression of relative humidity to the pollen amount yielded the equations of y = - 0,0831 x + 12795; with a negative correlation coefficient of R^2 of 0,00042 for the first year; and y = - 0,1865 x + 19,67; with a negative correlation coefficient of R^2 of 0,0347 for the second year (Fig. 6).

3.1.4. Wind Speed and Pollen Dissemination

Comparison of the wind speed recorded at 7^{00} a.m., 02^{00} p.m. and 09^{00} p.m. and the daily sums during the ‘entire’ and ‘maximum dissemination’ periods revealed that the pollen production was maximum when the wind speed was high (March 13, 15; April 3 in the first year and February 17, 27; March 7, 10, 19 in the second year) (Table 1, Fig. 5). The results of the regression analyses between the daily wind speed and the amount of pollen indicate a positive relationship; by the equations of y = 7,0878 x – 15126; with a positive correlation coefficient of R^2 of 0,0586 for the first year, and y = 6,3916 x – 3,0978; with a positive correlation coefficient of R^2 of 0,0345 for the second year (Fig. 6).

3.1.5. Discussion

The daily and hourly results have demonstrated that the phenological characteristics of *Alnus* pollen such as the onset, the total pollen output in the duration of flowering period are strongly related to the climatic factors of the area. Temperature plays the most important role during the period of pollen dissemination. A negative relationship between relative humidity and the amount of pollen exists implying that the dispersion of arboreal pollen requires low relative humidity. Pollen output is favoured by low values of relative humidity and high wind speed however is depressed in the case of heavy rainfalls. The release of pollen from the plant increases after short and slight rainfalls; however, it stops completeley following strong ones, because a heavy rainfall during the flowering period washes out pollen in the atmosphere. A positive relationship between wind speed and the amount of pollen shed exists. The relationship can be explained by the fact that air currents facilitate the opening of pollen sacs and hence ease the dissemination.

3.2. The Effect of Accumulated Temperature and Global Climatic Change

The sum of temperatures of an area is affective on both the peak abundances of pollen production during the period of dissemination and the timing of onset of maximum pollen production. The ‘sum’ of temperature, *i.e.*, ‘heat accumulation’, from the end of winter dormancy until the start of pollination determines the onset of pollen production. Accumulated daily temperatures from the first of January until the beginning of dissemination, *i.e.* the onset of pollen production of *Alnus* were 313°C and 260°C (avg. 287°C) in the years 1968 and 1969 in the İstanbul area (Tables 1 and 2). The Alder in the same area has required a 341°C temperature sum during the years 1944 to 1954 and 172°C in Trabzon area during 1981-1985.

The Alder required a total heat ranging from 183°C to 321°C (avg. 267°C) from the year 1995 to 2002 in Balıkesir, Bartın, Bursa, Denizli and Zonguldak. Accumulated temperature requirement of Alder shows a variation from a minumum of 172°C and to a maximum of 341°C, with a 169°C difference at different time periods and at different localities (Fig. 7).

According to the Emberger's climatic classification, the study site today has a 'cool' Mediterranean climate with a 'moderate' precipitation. The site has an average annual temperature of 12,8 ^{0}C and precipitation (P) of 1074 mm, the mean of the maxima of the hottest month (M) is 27 ^{0}C and the mean of the minima of the coldest month (m) is 1,5 ^{0}C. The summer precipitation (PE) (June-July-August) is 98 mm, drought index (S = PE/M) is 3,6 and the plviothermic quotient [$Q = 2000\ P / (M^2 – m^2)$ in ^{0}K] is 146,1. Comparison of the meteorological parameters of the cool period (1930-1968) with that of the second phase of the warming period (2000-2006) revealed that the average annual temperature in the İstanbul area has increased by 0,6 ^{0}C, total annual precipitation by 135 mm. An increase in the M, m, S and Q values have also occurred from 27 to 29 ^{0}C; from 1,5 to 1,7 ^{0}C; from 3,6 to 5,6 and from 146,1 to 154,7 respectively which resulted in a change of the climate of the study site from a 'Mediterranean' to a 'Sub-Mediterranean' nature. Similar increases in all the other nearby stations (Fig. 2) have also occurred in the range of an increase of 0,3-0,6 ^{0}C in average annual temperature, 12-19 % increase in annual precipitation (Appendix 2).

The onset of dissemination of *Alnus* pollen did not start earlier than the February 15th and did not end later than the April 30th in all the locations of this study (Table 2). An increase of 0,7°C in global temperature corresponds to 32,2°C until 15 th of February and a 84°C additional temperature until the beginning and ending of dissemination periods respectively. The minimum 172°C thereshold value then is expected to be exceeded in 5,3 years (172/32,2) and the maximum 321°C thereshold value in 9,9 years (321/32,2) (Table 2). In other words, the Alder pollen may start to an earlier dissemination within 5,3-9,9 years ahead under Turkey's climatic conditions. Similarly the ending of dissemination may be expected to change within 5,7 (479/84) and 6,8 (544/84) years. If an additional 51,8°C is added to the minimum 159°C and maximum 344°C temperature requirement of Alder during the dissemination period, then 3 (159/51,8) to 6,6 (344/51,8) years will be sufficient to cause phenological anomalies during the dissemination period.

4. Conclusions

The results of this study have demonstrated that the phenological characteristics of *Alnus* are strongly related to the climatic factors of the area. The daily and even hourly changes in the climatic variables have a strong effect on the dissemination of pollen. Among the factors, temperature plays the most important role and is followed by humidity, precipitation and wind speed.

Analysis of the climatic variables of the last fourty years of the study area and the nearby locations has shown that a 0,3-0,6 °C increase in average annual temperature and 12-19 % increase in annual precipitation have occurred consistent with the global climatic changes. The results of this study have revealed that the onset of pollen dissemination of Alder is within the tolerable limits at the present however, future projections show that the phenological and physiological requirements are expected to change within 3 to 10 years of period in accordance with the global climate.

Acknowledgements

The author is indebted to Dr.B. Aytuğ, Emeritus Professor of the Faculty of Forestry of İstanbul University for providing the pollen data.

References

Aytuğ, B., Aykut, S., Merev, N. and Edis, G., 1974. Pollinization in the Belgrad Forest and the environs of İstanbul. TBTAK Publications, 221, (TOAG Serial No. 29), 700 p.

Bıçakcı, A, Canıtez, Y., Öneş, Ü., Sapan, N., Malyer, H., 1999. Atmospheric pollen of İznik (Bursa). Ot. Systematical and Botanical Journal. 6 (1), 75-82.

Bıçakcı, A., Akyalçın, H., 2000. Analysis of airborne pollen fall in Balıkesir, Turkey, 1996-1997. Annals of Agricultural and Environmental Medicine. 7, 5-10

Browicz, K., 1987. Chronology of the Euxinian and Hyrcanian element in the woody flora of Asia. Plant Systematics and Evolution. 162, 305-314.

Celik, A., Güvensen, A., Uysal, İ. and Özturk, M., 2005. Differences in concentrations of allergenic pollens at different heights in Denizli, Turkey. Pakistan Journal of Botany. 37(3), 519-530.

Chen I-C, Hill, J.K., Ohlemüller, R., Roy, D.B., Thomas, C.D., 2011. Rapid range shifts ofspecies associated with high levels of climate warming. Science. 333,1024–1026

IPCC, 2007. The physical science basis. (In S Solomon, Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor, HL Miller, eds)., Climate Change. Cambridge University Press, New York

Kajba, D. and Gracan, J., 2008. Technical Guidelines for genetic conservation and use for Black Alder (*Alnus glutinosa*). Euforgen İnternational Plant Genetic Resources İnstitute, Rome, İtaly, 6 p.

Kaplan A., 2004. Airborne pollen grains in Zonguldak, Turkey 2001-2002. Acta Botanica Sinica. 46, 668-74

Kaya, Z. and Aras, A., 2004. Airborne pollen calendar of Bartin, Turkey. Aerobiologia. 20 (1), 63-67.

Kayacık, H., 1957. Phänologischer beobachtungen im Belgrader wald. 1943-1957. Review of the Faculty of Forestry, İstanbul University 7 (A-2), 21-36.

Kutluk, H. and Aytuğ, B., 2001. Vegetation versus climate in İstanbul. Plants of the Balkan Peninsula. into the next Millenium. Proceedings of the 2 nd Balkan Botanical Congress, İstanbul (ed.. N.Özhatay), 279-284.

Kutluk, H. and Aytuğ, B., 2010. Airborne pollen flora of a deciduous mesic forest in Turkey. Bangladesh Journal of Plant Taxonomy. 17 (1), 23-31.

Küçük, M., 1986. Phenological observations in Maçka-Meryemana basin. Journal of Forestry Research. 32 (64), 87-110.

Lenoir J, Gégout J.C., Marquet P.A., de Ruffray P. and Brisse H., 2008. A significant upward shift in plant species optimum elevation during the 20th century. Science. 320,1768–1771

Menzel, A. and Fabian, P., 1999. Growing season extended in Europe. Nature. 397, 659

Parmesan, C., 2006. Ecological and evolutionary responses to recent climate change. Annual Review Ecology & Evolutionary Systematics. 37, 637–669

Parmesan, C. and Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature. 423 (2), 37-42.

Pérez, C. F., Gardiol, J. M. and Paez, M.M., 2003. Comparison of diurnal variation of airborne pollen in Mar del Plata (Argentina). Grana. 42, 161-167.

Peternel, R., Srnec,L., Hrga, İ., Hercog, P. and Ulig, J., 2005. Airborne pollen of *Betula*, *Corylus* and *Alnus* in Zagreb, Croatia. A three-year record. Grana. 44 (3),187-191.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S.H., Rosenzweigl, C.and Pounds, J.A., 2003. Fingerprints of global warming on wild animals and plants. Nature. 421 (2), 57-60.

Spieksma, F.Th. M., Frenguelli, G., Nikkels, A. H., Mincigrucci, G., Smithuis, L. O. M. J. and Bricchi, E., 1989. Comparative study of airborne pollen concentrations in central İtaly and The Netherlands (1982–1985) emphasis on *Alnus*, Poaceae, and *Artemisia*. Grana. 28, 25–36.

Thuiller, W., Alberta,C., Araújo, M.B., Berry, P.M., Cabezad, M., Guisane, A., Hicklerf, T., Midgleyg, G.F., Paterson, J., Schurrh, F.M., Sykesf, M.T. and Zimmermanni, N.E., 2008. Predicting global change impacts on plant species' distributions: Future challenges. Perspectives in Plant Ecology, Evolution and Systematics. 9, 137-152

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesank, C., Beebee, T.J.B., Fromentin, J.M., Hoegh-Guldberg, O. and Bairlein, F., 2002. Ecological responses to recent climate change. Nature. 416, 389-395

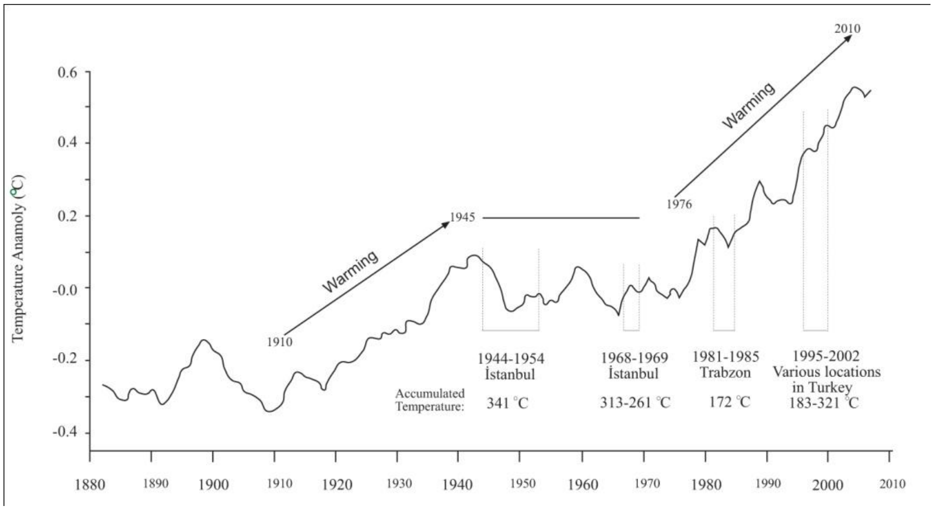


Figure 1: Global Temperature Anamoly in the Last Century

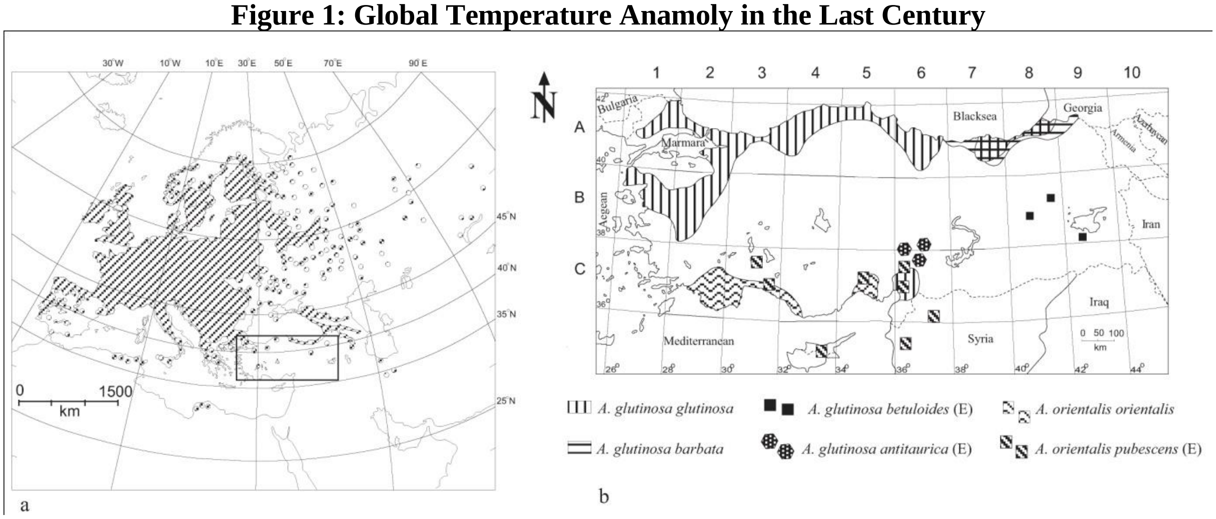


Figure 2: A: Distribution of *Alnus glutinosa* in the Northern Hemisphere (Euforgen, 2013); B: Distribution of the *Alnus* in Turkey

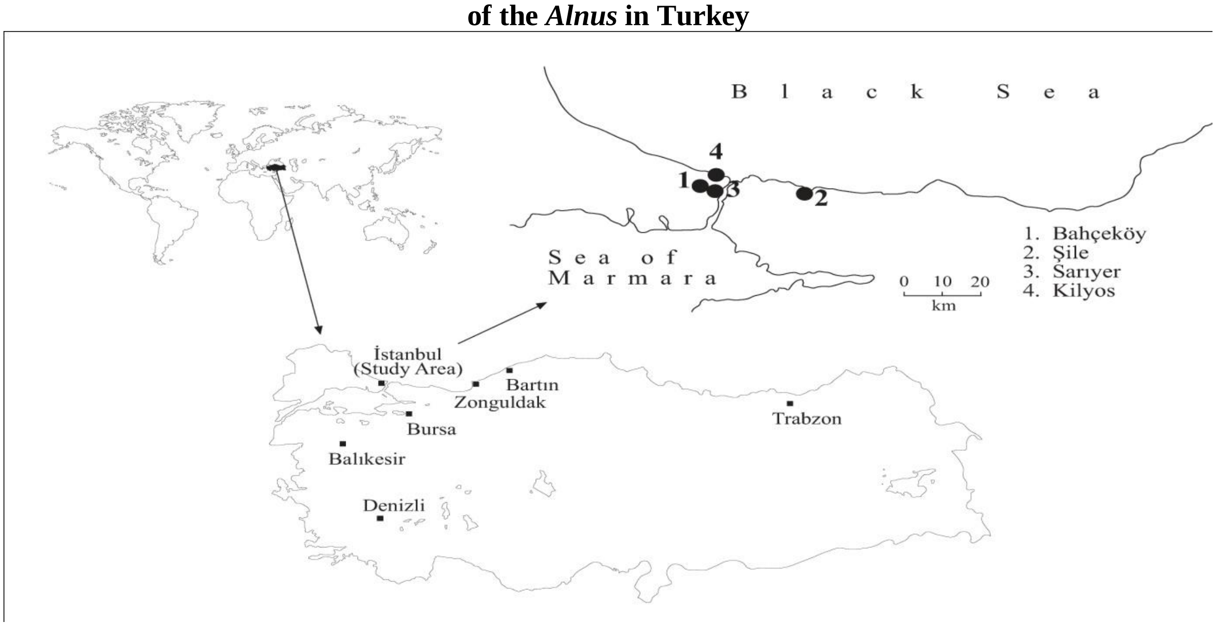


Figure 3: Map Showing the Locations in The Text

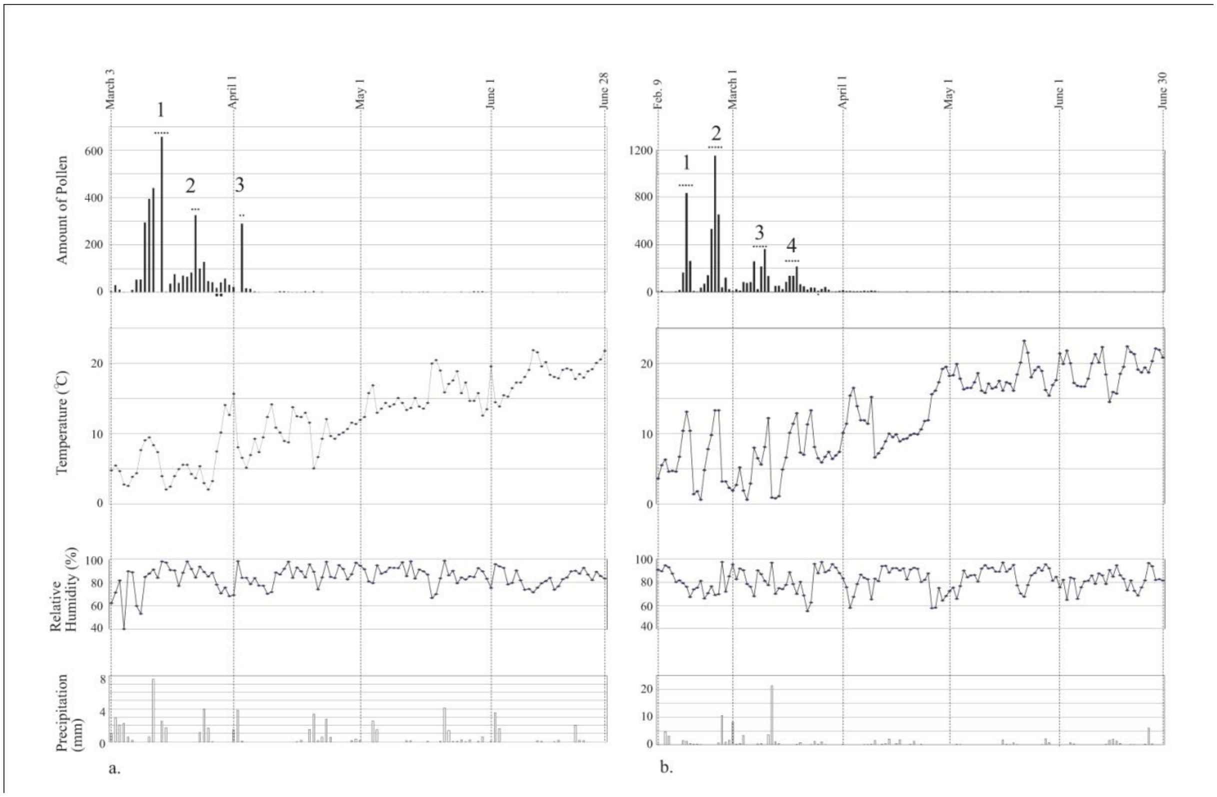


Figure 4: Amount of *Alnus* Pollen and Temperature, Relative Humidity and Precipitation in the İstanbul Area (1968, 1969)

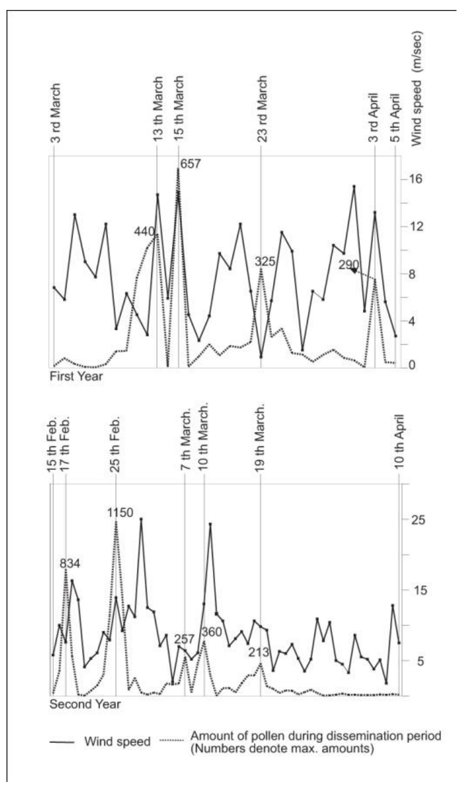


Figure 5: Amount of Pollen and Daily Wind Speed

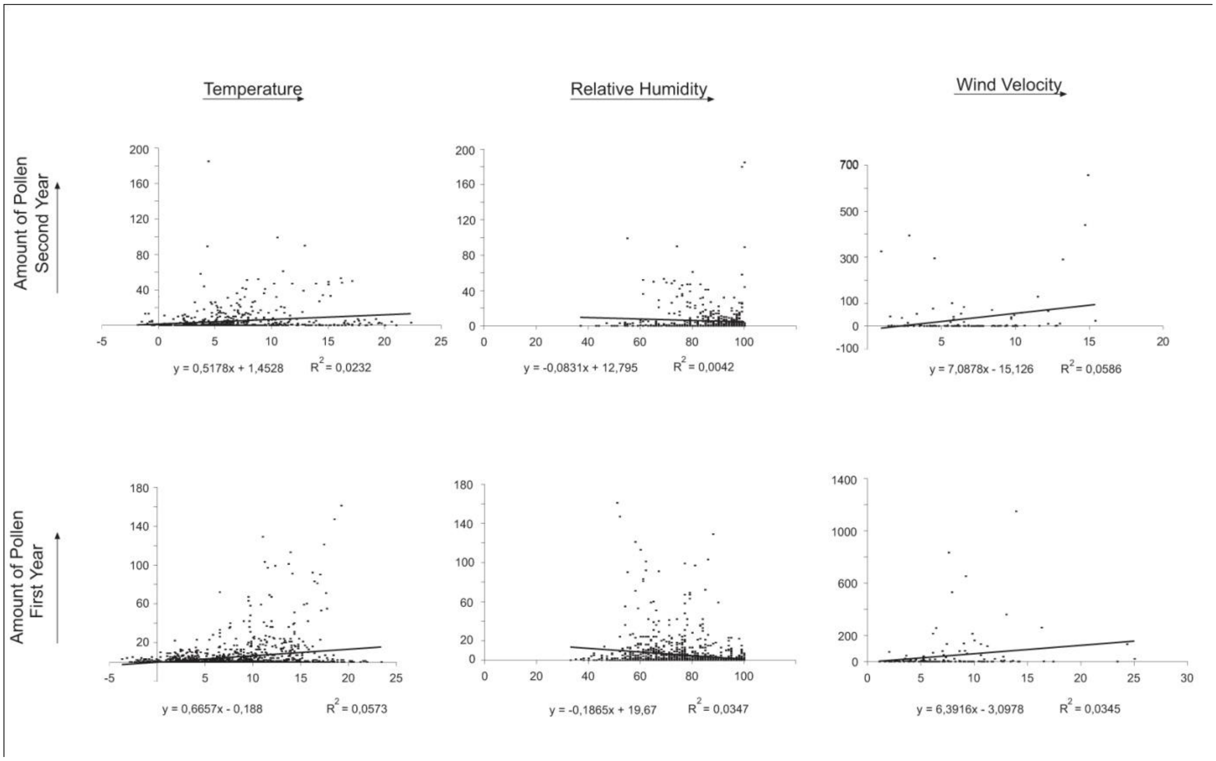
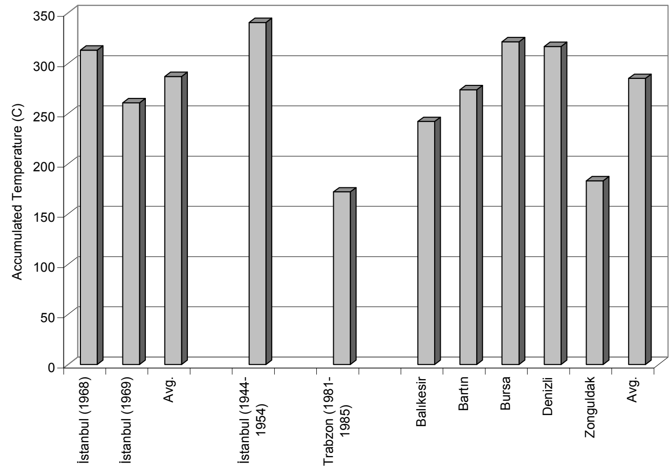
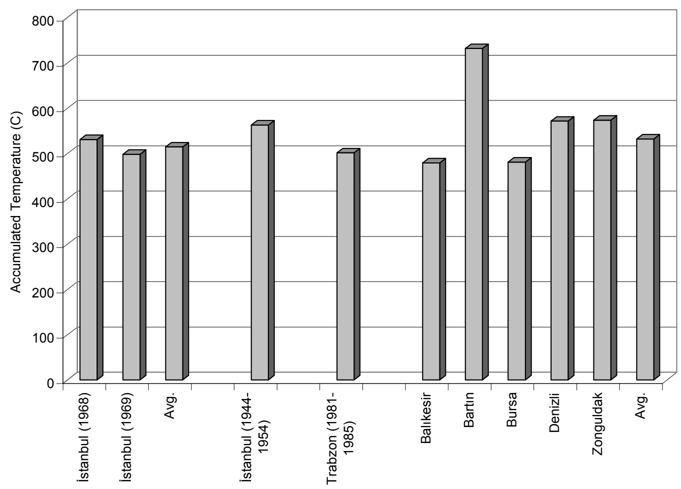


Figure 6: Regression Analysis between the Amount of Pollen and Temperature, Relative Humidity and Wind Speed in the İstanbul Area

A:



B:



C:

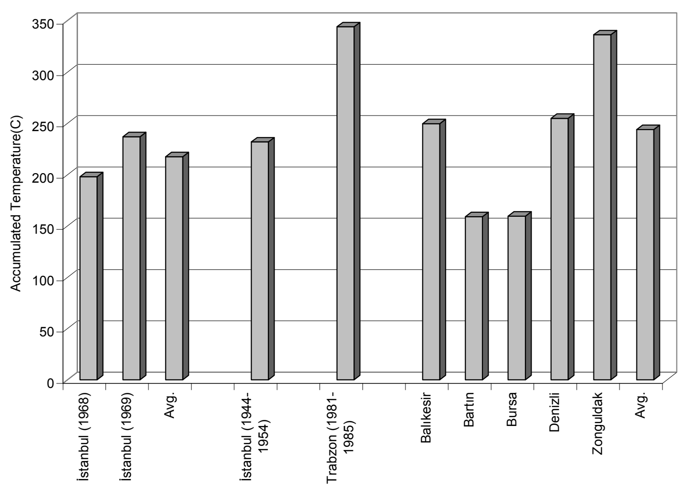


Figure 7: Accumulated Temperature of *Alnus* from Different Time Intervals and from the Areas of Different Climatic Settings in Turkey (A: Until the Beginning of Pollen Dissemination; B: Until the End of Pollen Dissemination; and C: During Pollen Dissemination Period)

Table 1: Summary of the Airborne *Alnus glutinosa* Pollen and Temperature and Wind Speed from the Study Area

	1 st Year	2 nd Year	Total
Pollen dissemination period (days)	March 3-June 28 (118 Days)	Feb. 9-June 30 (143 Days)	
Number of pollen	3515	6399	9914
Maximum dissemination period (days)	March 4-April 5 (33 Days)	Feb. 15-April 10 (56 Days)	
Number of pollen during maximum dissemination period and (percentage)	3451	6347	9624
Accumulated temp. from January 1 st. until beginning of maximum dissemination period (^0C)	313	260	
Accumulated temperature from January 1 st. until end of maximum dissemination period (^0C)	531	498	
Accumulated temp. during maximum dissemination period (^0C)	198	237	
Sum of wind velocity at 7°°-14°°-21°° during maximum dissemination (m/sec)	73-125-54	117-214-144	

Table 2: Accumulated Temperature of *Alnus* from Different Time Intervals and from the Areas of Different Climatic Settings in Turkey

1	2	3	4	5	6	7	8	9	10	11	12	13
1968-1969	İstanbul	129	1968	1	0,55	Aytuğ et al., 1974 & This study	3 March	5 April	313,1	531,1	198	
	İstanbul	129	1969	1	1	Aytuğ et al., 1974 & This study	15 Feb	25 March	260,6	498,1	237	
								Avg.	286,8	514,6	217,5	
1944-1954	İstanbul		1944-1954	10		Kayacık, 1957	10 March	10 April	340,6	563	231,9	
1981-1985	Trabzon	1100	1981-1985	5	No Data	Küçük, 1986	11 March	29 April	171,9	501,5	344,1	
Recent	Balıkesir	147	1996, 1997	2	0,59	Bıçakcı and Akyalçın, 2000	15 February	21 March	242	479,1	249,6	14,5
1995-2002	Bartın	30	1995, 1996, 1997	3	0,58	Kaya and Aras, 2004	1 April	15 April	273,5	731,9	159	13,1
	Bursa	15	1997	1	1,06	Bıçakcı et al., 1999	21 February	15 March	321,4	481	159,6	14,4
	Denizli	428	2000	1	0.11	Çelik et al. 2005	21 February	21 March	316,7	571,5	254,8	15,8
	Zonguldak	136	2001, 2002	2	2,3	Kaplan, 2004	21 January	15 March	182,9	573,7	336,3	12,8
								Avg.	267,3	567,4	231,8	

1: Time interval (Years); 2: Province; 3: Elevation (m); 4: Study year; 5: Duration of study (Years); 6: Pollen percentage within the airborne assemblage; 7: Source; 8: Beginning of pollen dissemination (Months); 9: Ending of pollen dissemination (Months); Accumulated temperature 10: until the beginning of pollen dissemination; 11: until the end of pollen dissemination; 12: during pollen dissemination period; 13: Average annual temperature

Appendix 1: Amount of Airborne *Alnus glutinosa* Pollen and Meteorological Parameters during the Dissemination Period in İstanbul Area

Month	Day	Temperature ^0C	Relative Humidity (%)	Precipitation (mm)	Wind Velocity at 07^{00}	Wind Velocity at 14^{00}	Wind Velocity at 21^{00}	Sum of Wind Velocity	Total Pollen Count	Hours of No count	Temperature ^0C	Relative Humidity (%)	Precipitation (mm)	Wind Velocity at 07^{00}	Wind Velocity at 14^{00}	Wind Velocity at 21^{00}	Sum of Daily Wind	Total Pollen Count	Hours of No count
Feb.	09										3,6	90,6	0,1	0	2,8	2,2	5	1	
	10										5,5	89,3	0	0	2,5	1,5	4	11	
	11										6,3	94,4	4,7	2,2	2,2	2,3	6,7	0	
	12										4,6	92,8	3,1	0,9	1,8	0,7	3,4	0	
	13										4,7	87,3	0	3,9	2,2	3	9,1	0	
	14										4,6	80	0	0	1,7	0	1,7	3	
	15										6,7	81,5	0	0	3,6	2,2	5,8	**16**	
	16										10,4	79,1	1,42	3,6	4,5	1,9	10	**162**	
	17										13,1	76	1,16	2,2	2,4	3	7,6	**834**	
	18										10,4	67,2	0,34	4,8	4,7	6,8	16,3	**260**	
	19										1,4	73,8	0,18	5,5	5,1	3	13,6	**7**	

	20										1,8	75,2	0,14	2,2	1,9	0	4,1	**1**	
	21										0,6	81,1	0,04	0	3,2	2,1	5,3	**33**	
	22										4,8	66	0	1,2	4,1	0,8	6,1	**68**	
	23										7,8	70,5	0	2,6	4,8	1,6	9	**139**	
	24										9,8	76,4	0	1,1	5,5	1,3	7,9	**531**	
	25										13,3	68,9	0	3,1	6,5	4,3	13,9	**1150**	
	26										13,3	69,7	0,57	1,8	3,1	4,3	9,2	**653**	
	27										3,2	97,3	10,48	5,4	3,5	3,8	12,7	**37**	
	28										3,2	71,8	0,81	3,1	4,5	3,6	11,2	**118**	
	29										2,3	85	1,58	7,4	7	10,6	25	**21**	
March	01										1,9	95,2	8,13	3,1	5,4	4	12,5	**7**	
	02										2,7	82,4	0,15	2,2	4,2	5,5	11,9	**21**	
	03	4,8	62,2	1,01	2,4	3,6	0,8	6,8	4		5,2	91,6	0,34	2,4	1,3	3,4	7,1	**11**	
	04	5,5	71,3	2,9	2,2	2,2	1,4	5,8	**30**		1,9	90,2	3,31	5,1	2,1	1,4	8,6	**81**	
	05	4,7	81,7	2,06	6,9	4,8	1,3	13	**11**		0,6	78,4	0	0	2	0	2	**74**	
	06	2,8	40	2,23	2,2	3,4	3,4	9	**1**		2,9	76,1	0	0	5,7	1,3	7	**81**	
	07	2,6	89,6	0,58	4,2	3,5	0	7,7	**0**		8	67,9	0	2,5	2,6	1,3	6,4	**257**	
	08	3,9	88,7	0,19	3,9	4,6	3,7	12,2	**10**		6,5	90,1	0,21	0	3,1	2,1	5,2	**21**	
	09	4,4	59,8	0	0	2,7	0,6	3,3	**53**		5,6	86,9	0,3	3,6	1,5	1	6,1	**214**	
	10	7,7	53,1	0	0	6,3	0	6,3	**54**		8,1	81,1	0	0	7,8	5,2	13	**360**	
	11	9,1	84,7	0	0,9	2,4	1,2	4,5	**295**		12,2	77,4	3,49	5,4	14,1	4,8	24,3	**133**	
	12	9,5	87,6	0,58	0,9	1,9	0	2,8	**394**		0,9	96,7	21,24	4,6	3,8	3,2	11,6	**0**	
	13	8,4	91	7,57	2,1	7,1	5,5	14,7	**440**		0,8	70	1,05	2,1	3,1	5,4	10,6	**50**	
	14	7,4	84	0	1,9	2,6	1,4	5,9	**1**		1,1	74,8	0,29	0	4,4	2,7	7,1	**51**	
	15	4	98	2,49	6,5	5,4	3	14,9	**657**		4,9	74	0	1,9	5,4	0,8	8,1	**22**	
	16	2,1	97	1,7	2	1,8	0,7	4,5	**2**		6,6	77,7	0	0	5,5	3,6	9,1	**83**	
	17	2,5	90,6	0	0	1,2	1,1	2,3	**36**		10,1	88,5	0	2,2	3	2,2	7,4	**135**	
	18	4	90,3	0	0	1,4	3	4,4	**76**		11,4	78,3	0	2	5,9	2,7	10,6	**134**	
	19	5	77	0	4,1	3,7	1,9	9,7	**39**		12,9	69,9	0,08	0	5	4,8	9,8	**213**	
	20	5,6	88,3	0	2,1	4,1	2,2	8,4	**70**		7,3	80,3	0,7	4,2	3,3	1,8	9,3	**63**	
	21	5,6	98	0	3,8	3,5	4,9	12,2	**65**		7	68,6	0	1,4	2,2	0	3,6	**46**	
	22	4,3	91,5	0	2,4	1,9	2,2	6,5	**83**		11,3	55,1	0	1,2	5,1	0	6,3	**18**	
	23	3,7	84,2	0	0	0,9	0	0,9	**325**		13,3	62,5	0,04	1,3	4,7	0	6	**35**	
	24	5,4	93,5	1,12	0	5,7	0	5,7	**100**		8,1	95,7	1,08	0	4,5	2,8	7,3	**33**	
	25	3	89	3,99	5,6	4,9	1	11,5	**128**		6,5	87,6	0,13	1,4	2,7	1,2	5,3	**9**	10
	26	2,1	85,1	1,69	4	3,8	2,1	9,9	**47**		5,9	97,3	0,95	0	2,3	1,2	3,5	**24**	
	27	3,3	88,4	0,02	0	1,5	0	1,5	**42**		6,7	88,5	0,03	1,7	2,1	1,4	5,2	**40**	
	28	7,5	78,1	0	0	4,3	2,2	6,5	**18**	18	7,4	90	0	4	2,4	4,5	10,9	**18**	
	29	10,2	70,6	0	1,9	3,2	0,7	5,8	**41**	14	6,4	95,5	0	2,7	2,1	3	7,8	**1**	
	30	14,1	75,6	0	3,2	5,1	2,1	10,4	**58**		6,9	92,4	0	1,8	4,2	4,4	10,4	**2**	
	31	12,7	68,2	0	2,7	7	0	9,7	**31**		7,4	87,8	0	2,2	1,3	1,5	5	**7**	
April	01	15,7	69,1	1,46	2,3	10,7	2,4	15,4	**23**		10,1	83,2	0,07	2,2	2,3	0	4,5	**14**	
	02	8,1	98,2	3,82	1,1	2,7	1	4,8	**0**		11,4	75,6	0	1,3	1,2	0,8	3,3	**6**	
	03	6,6	83,9	0,08	4,6	6,2	2,4	13,2	**290**		15,4	58	0	2,6	4,2	1,8	8,6	**7**	
	04	5,2	84	0	1,6	2,2	1,8	5,6	**17**		16,5	67,3	0	2,1	3,4	0	5,5	**4**	
	05	7	78,5	0	0	2	0,7	2,7	**14**		13,9	78,3	0	0	2,2	3	5,2	**5**	
	06	9,3	83,7	0	0,5	2,4	0	2,9	3		11,9	86,5	0	0	2	1,8	3,8	**5**	
	07	7,4	77,3	0	4,6	3,2	1,6	9,4	1		11,9	83,7	0,03	1,4	2,3	1,4	5,1	**9**	
	08	9,5	77,2	0	0,5	2,4	0	2,9	.	24	11,4	82,4	0,03	0	1,8	0	1,8	**6**	
	09	12,4	70,3	0	2,2	4,4	0	6,6	.	24	15,2	65,2	0,11	1,2	4,9	6,7	12,8	**10**	
	10	14,2	71,7	0	2	3,8	4,3	10,1	0		6,6	83	1,42	2,8	2,5	2,2	7,5	**7**	
	11	10,9	88,5	0	2,1	3,4	2	7,5	1		7,2	80,8	0	0	2,7	4,8	7,5	1	
	12	10,2	86,8	0	1,4	4,8	3,8	10	4		7,9	93,7	0,1	2,2	2,6	0	4,8	0	6
	13	9	91,7	0	1	2,2	2,2	5,4	4		8,9	94	0,29	1,4	3,3	1,6	6,3	0	
	14	8,8	97,8	0	2,9	3,8	1,8	8,5	2		10	88,2	2,04	1,3	2,3	2,9	6,5	0	
	15	13,8	84	0	1,3	4,8	1,6	7,7	1		9,5	91,9	0	4,6	4,7	4,9	14,2	0	4
	16	12,5	92,8	0,01	3,4	2,2	0,9	6,5	1		9,9	92	0,36	3,9	6,6	2,9	13,4	0	

	17	12,4	89,5	0,19	1,9	6	1	8,9	1	1	8,9	90	1,69	4,9	3	1,2	9,1	1	
	18	13	84,3	0	0	3,6	0	3,6	3	18	9,2	91,8	0	1,3	2,4	2,1	5,8	0	
	19	11,6	95,5	1,5	0	3	2,2	5,2	1		9,3	82,3	0	5,8	7,4	3,3	16,5	2	
	20	5,1	89,2	3,37	2,3	3,1	0,7	6,1	5		9,8	90,8	0,08	3,5	3,4	2,8	9,7	0	
	21	6,7	74	0,14	0,9	3,1	2,1	6,1	.	24	10	92,3	1,08	3,9	3,8	2,2	9,9	0	
	22	9,3	84,3	0,57	2,4	9	1,4	12,8	2		9,9	91,5	0	2,1	3,1	1,8	7	0	
	23	12,1	97,7	2,73	3,9	1,8	3,1	8,8	0	6	10,6	80,1	0,07	3	2,9	0	5,9	0	
	24	9,7	84,7	0,55	2,5	4,4	0,9	7,8	0	8	11,8	82	0	0	3,2	2,4	5,6	0	
	25	9,3	83,8	0	0	3,8	0	3,8	0	6	11,9	87,5	0	2	2,2	0	4,2	1	
	26	9,9	94,8	0	2,7	3,5	3,1	9,3	0	5	15,6	57,7	0	0	1,7	1,3	3	0	
	27	10,2	91,5	0	2,6	3,4	1,6	7,6	0	8	16,1	58,1	0	0	2,6	0	2,6	.	24
	28	10,7	82,6	0	2,2	2,4	2,2	6,8	0		17,3	75	0	1,2	2,6	0	3,8	0	
	29	11,6	87	0,15	1,3	2,2	1,3	4,8	0		19,2	64,2	0	0	4,4	0	4,4	3	
	30	11,4	96,9	0,31	1,2	3,4	1,1	5,7	0		19,5	68,1	0	1,6	2,3	0	3,9	0	1
May	01	12	94,3	0,16	0	1,8	1,3	3,1	0		18,2	72,3	0	1,2	0,2	0,2	1,6	4	
	02	12,4	91,3	0	0	1,9	0,5	2,4	0		18,3	75,3	0	0	2,9	0	2,9	2	
	03	15,8	80,9	0	3,4	2,8	0	6,2	0	10	19,9	65,7	0,13	0,7	2,9	0	3,6	4	
	04	16,9	79,4	2,52	1,7	2,1	1,6	5,4	1		17,8	76,6	0,04	1,3	1,7	0	3	0	
	05	13	94,6	1,46	0	2,2	0	2,2	0		16,3	89,9	0	2,2	3,3	2,2	7,7	0	
	06	13,6	87,5	0	2,2	2,7	2,1	7	0		16,5	84,2	0	1,6	2,7	4,4	8,7	2	
	07	14,4	89	0	0	3,8	1,5	5,3	0		16,5	85,8	0	2,2	3,9	3	9,1	0	
	08	13,9	92,8	0	2,1	3	2,7	7,8	0		17,3	86,1	0	2,1	1,9	1,2	5,2	0	
	09	14,2	92,5	0	1,2	2,2	2,4	5,8	0		18,6	80,4	0	0	2,2	0	2,2	0	
	10	15,1	92,3	0	1,2	2,4	3,6	7,2	0		16,1	91,6	0	2,3	2,2	2,2	6,7	0	
	11	14,4	97,3	0	1,2	2,2	0,8	4,2	2		15,8	94,5	0	3,4	3,7	1,6	8,7	1	
	12	13,4	85,4	0,14	5,3	5,8	1,6	12,7	1		17,1	91,7	0	2,7	2,2	2,2	7,1	0	
	13	13,7	98,1	0,14	1,1	4,2	2,1	7,4	1		16,4	92,5	0	3	2,2	3,8	9	2	
	14	15,1	83,3	0	2,4	4,6	2,9	9,9	0		16,6	89	0	2,4	3,4	0	5,8	0	
	15	13,9	91	0	5,1	4,2	2,3	11,6	1		17,5	89	0	4,5	2,4	2,6	9,5	1	
	16	13,6	89,5	0	1,4	1,2	0	2,6	2		16,1	96,8	1,67	1,3	7,4	2,2	10,9	0	
	17	14,4	86,7	0,03	1,7	1,8	0	3,5	2		17,3	88,9	0,1	0	2,1	2,2	4,3	0	
	18	20	66,7	0	0	0,9	1,1	2	0		17,1	91,3	0,03	2	2,1	1,4	5,5	0	
	19	20,5	70	0	0,7	3,9	3,1	7,7	0		16,1	94,8	0,59	2	6,2	1,2	9,4	0	
	20	19	83,5	0,03	2,2	2,2	2,2	6,6	0		18,4	77,2	0,03	1,4	1,6	2,4	5,4	.	24
	21	15,9	98,6	4,09	1,6	4,3	0	5,9	1		20,1	70,2	0	0	2,7	0	2,7	3	
	22	17,1	86,1	1,4	0	1,8	0	1,8	0		23,2	67,4	0	0	1,3	0,7	2	1	
	23	17,6	89,9	0,05	2,6	4,1	0,9	7,6	0		21,5	77,5	0	1,3	2,4	1,7	5,4	2	
	24	18,9	79,3	0,03	3,9	3,9	1,6	9,4	.	24	18	85,8	0	2,5	2,5	2	7	0	
	25	15,8	84,2	0,23	4,2	4,7	1,7	10,6	2		19	87,8	0	3,6	2	3,1	8,7	0	
	26	17,3	82,5	0,02	2,1	4,3	1,1	7,5	0		19,5	92,5	0	3	4,6	3,1	10,7	0	
	27	14,7	85,2	0,23	4,5	1,7	0,6	6,8	1		18,9	89,8	0,02	4,4	7,5	5,5	17,4	0	
	28	14,7	84,6	0	0	2,5	0	2,5	4		16,2	95,3	2,08	2,4	2,9	5,5	10,8	0	
	29	15,8	92,3	0,05	0	1,6	0	1,6	3		15,4	91,8	0,68	1,8	2,3	1,4	5,5	0	
	30	12,6	89,5	0,62	3,8	4,1	1,5	9,4	4		16,9	81,2	0	0	2,4	3,9	6,3	0	
	31	13,5	83,1	0	0	2,4	0	2,4	1		17,6	84,5	0	2,3	2,4	1,7	6,4	0	
June	01	19,6	75,3	0,07	0	1,8	0,9	2,7	0		21,4	75,5	0	0	3,9	1,3	5,2	1	
	02	14,5	95,7	3,52	3	2,2	1	6,2	0		19,9	82	0	1,2	2,2	0	3,4	0	
	03	13,9	93,8	1,59	2,7	2,4	1,7	6,8	0		21,8	64,8	0	2,1	3	5,4	10,5	1	
	04	15,5	92,5	0	4	2,4	2,2	8,6	0		20	84	0,64	4,4	6,3	3,4	14,1	0	
	05	15,3	78,3	0	1,3	2,2	0	3,5	0		17,2	83	0,21	3,6	4,9	2,7	11,2	0	
	06	16,5	79,6	0	0	2,2	2,1	4,3	0		16,8	65,7	0	5,8	12,2	5,4	23,4	0	
	07	17,3	90,3	0	2,2	2,2	1,6	6	0		16,7	75,6	0	4,5	4,1	3,1	11,7	0	
	08	17,3	81,8	0	1,9	2,6	1,6	6,1	0		16,7	80,7	0	3,5	3,3	1,4	8,2	0	
	09	18,1	73,7	0	0	1,7	0,8	2,5	0		17,8	81,2	0	2,9	2,2	0,8	5,9	0	
	10	19,1	74,4	0	0,8	1,8	2	4,6	0	1	20	85,7	0	1	1,2	0	2,2	0	
	11	21,9	71,5	0	0	1,7	1,8	3,5	1		21,3	78,5	0	0	1,2	0,9	2,1	1	
	12	21,6	75,5	0,13	1,3	3,8	2,2	7,3	0		20,1	87,4	0	2,7	1,3	2,6	6,6	0	

	13	19,6	79,3	0,04	1,9	3,3	3,6	8,8	0		22,3	85,8	0	2	2,1	0	4,1	1	
	14	20,2	81,2	0	1,4	1,6	1,2	4,2	0		18,4	78,4	0,09	3,7	5,7	3,2	12,6	0	
	15	18,4	84	0	0,9	3,1	0	4	0		14,5	90,4	1,53	1,4	3,1	2,7	7,2	0	7
	16	18,1	73,8	0,02	1,3	2,6	1,5	5,4	0		15,9	84,7	1,89	1,2	3,6	0	4,8	0	6
	17	17,9	76,7	0,2	0	1,6	0	1,6	1		15,7	94,4	1,33	0	2	0	2	0	
	18	19,1	82,8	0	0	1,4	0	1,4	1		18,5	85,9	0,43	2,8	2,1	1,2	6,1	0	
	19	19,3	84,2	0	1,2	2,2	1	4,4	1		19,5	82,8	0	0	1,6	0	1,6	0	
	20	19,1	89,5	0	0	2,6	1,2	3,8	0		22,4	73	0	0	1,1	0	1,1	0	
	21	17,8	90	2,04	3	3,1	0	6,1	0		21,6	81,5	0,03	1,8	2,8	0,8	5,4	0	
	22	18,5	87,5	0,2	0,9	1,8	0	2,7	0		21,3	72,6	0,01	4,2	3	1,4	8,6	1	
	23	18	92,6	0,13	3,4	3,9	1,1	8,4	0		19,1	68,5	0	1,5	2,4	2,6	6,5	0	
	24	18,9	86,7	0	3	2,7	1,4	7,1	0		18,7	75,5	0	2,7	4	3,2	9,9	0	
	25	19,2	82	0	2,3	4,9	2,6	9,8	0		19,4	81,5	0,2	2,7	3,9	2,4	9	0	
	26	20,1	89,1	0	2	1,8	0,8	4,6	0		18,7	96,4	5,96	2,2	3,4	1,5	7,1	0	
	27	20,6	85,5	0	1,3	1,7	1,4	4,4	0		20,3	93,6	0,22	1,9	1,5	2,8	6,2	1	
	28	21,8	83,3	0	0	3	3	6	1		22,1	81,9	0	7,8	4,2	0,7	12,7	0	
	29										21,9	82,5	0	1,2	0,7	0,6	2,5	0	
	30										20,8	81,4	0	0	3,9	3,7	7,6	1	
Total		1504			217	378	170		3515		1818			293	482	303		6399	

Appendix 2: Meteorological Characteristics of the Study Area during 1930-1968 and 2000-2006

1	2	3	4	5	6	7	8	9	10	11	12
Station	m,	Latitude-Longitude	°C	P mm,	P.Regime	S	M	m	Q		
Bahçeköy I	129	41°10‘K-29°03‘D	12,8	1074	WFSpSm	3,6	27	1,5	146,1		
Bahçeköy II			13,4	1209	WFSpSm	5,5	29	1,7	154,7	0,6	12
Kilyos I	30	41°18‘K-29°00 ‘D	13,9	717,3	WFSpSm	2,9	27	2,8	104,3		
Kilyos II			14,2	855,8	WFSpSm	3,8	29	2,8	113,1	0,3	19,3
Sarıyer I	56	41°07‘K-29°04‘D	13,8	752,5	WFSpSm	2,9	26	2,8	111,4		
Sarıyer II			14,1	895,5	WFSpSm	4,1	28	3	123,6	0,3	14,3
Şile I	31	41°10‘K-29°36‘D	13,6	747,1	WFSpSm	3,1	26	2,7	111,1		
Şile II			13,8	880,1	WFSpSm	4,9	28	2,6	121,2	0,3	13,3

I: 1930-1968 (38 Years)
II: 2000-2006 (7 Years)

1 Station
2 Elevation (m)
3 Coordinates
4 Average annual temperature (°C)
5 Average annual precipitation (P)(mm)
6 Distribution of precipitation wrt four season (Winter W, Fall F, Spring Sp, Summer Sm)
7 Drought Index (S = Summer precipitation / Mean of the maxima of the warmest month M)
8 Mean of the maxima of the warmest month (°C) (M)
9 Mean of the minima of the coldest month (°C) (m)
10 Plviothermic quotient (Q = 2000 P / M2- m2) (°K)
11 Temperature increse (°C)
12 Precipitation increase (%)