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Global Warming Leading to Phenological Responses in the Process of Urbanization, South Korea

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Abstract: Current studies are either region-limited, sole-species, or have short researching periods; so, studies about various species are necessary throughout South Korea. In this study, trends of changes in the budding and flowering dates of spring plants by climate factors served to explore the process of urbanization. Four common species, such as *Forsythia koreana* (forsythia), *Rhododendron mucronulatum* (azalea), *Prunus yedoensis* (Yoshino cherry) and *Prunus mume* (Japanese apricot), are examined during the period from 1973 to 2008 due to the limitation of recent datasets. Budding of forsythia, azalea, Yoshino cherry and the flowering of Japanese apricot are defined as Type I (inland, of reverse letter 'L') and flowering of forsythia, azalea and Yoshino cherry were grouped as Type II (inland and south coastline). *Prunus mume* budding was different from others, so it was defined as Type III (subtropical climate). The inland phonological response is relatively cold and dry and areas are affected by the Siberian high atmospheric pressure. On the other hand, the south and east coastlines are humid and warm areas even in the winter season due to the southeastern wind. There were advancements for 3.1 days of forsythia, 5.5 days of azalea, 6.5 days of Yoshino cherry and 18.6 days of Japanese apricot during the research period. The greatest changes occurred with respect to the minimum temperature in January and the maximum temperature in February, while the precipitation change was not significant. However, in Type II, the precipitation significantly impacted plant flowering events. Precipitation was the lowest in early spring in South Korea and especially the flowering of plants was impacted by the small amount of precipitation in this region. Additionally, if precipitation after budding was over 1 mm for forsythia and azalea, 2 mm for Yoshino cherry and 7 mm for apricot, flowering occurred in over 80% of the region. South Korea is characterized as having a small amount of land and a high population density in cities. As such, it encounters strong influences due to global warming, as well as urbanization. Seven metropolitan cities and Suwon have populations over 1 million and showed more remarkable phenological events and changes of climate factors than the other regions. Especially in the case of shrubs, the phenological events were delayed in urban areas during this research. In conclusion, climate change, as well as urbanization, serve as strong factors leading to phonological and regional events in the ecosystem.

Keywords: phenology; urban ecosystem; global warming; forsythia; sustainability; azalea

1. Introduction

According to the fourth assessment report of the Intergovernmental Panel on Climate Change [1], temperatures over the past five decades have doubled (approx. 0.13 °C/decade), compared with temperature increases (approx. 0.07 °C/decade) over the past hundred years (1906–2005). Since the 1850s, the 12 years (1990, 1995, 1997–1999, 2000–2006) with record-breaking high temperatures have all occurred after 1990 and these are ongoing events even now [1]. Additionally, precipitation has shown fluctuating trends that depend on various regions, where Northern European and Northern and Central Asian regions have increasing precipitation and Mediterranean, Southern Asian and Southern African regions are dry [1].

This phenomenon of climate change has recently been attracting attention since the changes of ecosystems and frequent extreme events have appeared due to global warming. Global warming has already produced significant impacts on many ecosystems [2]. Plants and animals that are being affected by global warming are commonly used for phenological dynamics [3–5]. It is very clear that several studies have discovered the global warming impacts on phenological events with respect to flowering [6–8] leaf unfolding, leaf fall, growth periods and fruiting [8], bird migration and breeding [9,10], insect appearance [11], amphibian phases [12] and fish phases [13] throughout the world. Phenological phenomena are very different for each species and each site and the phenological responses by each species are changing at various ratios [14,15]. Additionally, plants' and animals' phenological events have been advanced and those species are projected to change distributions because of warming in cooler areas [16].

South Korea is no exception. Recent annual mean temperatures and precipitation in South Korea showed increasing trends and frequent extreme events due to climate change caused by global warming. Several studies are under development regarding phenological events, along with climate change in South Korea. In Seoul, shrubs and trees showed an advancement in spring bloom by 12 to 20 days, associated with a 2 °C warming over the 83 years [17]. Flowering dates were advanced 0 to 41 days for eight species in Busan, from 1921 to 2007, compared with daily temperatures. The changes of the cherry blossom flowering dates due to temperature were advanced six to 13 days at 12 weather stations from 1973 to 2002. Budding events appeared seven days earlier and flowering appeared 10 days ahead in urban areas, as compared to rural areas, from 1997 to 1998 [18].

Climate changes can occur not only because of global warming but also due to urbanization—small-scale studies with respect to cities have been conducted [19]. The surfaces of cities are covered with buildings, paved roads, etc., creating changes in the energy balance [20,21]. Additionally, the water balance can be changed due to increasing evaporation levels. There are many studies published that such urbanization phenomena recently advanced phenological events [22,23]. In particular, population increase affects the atmospheric environment [20] and high population-density cities show a more remarkable influence. Human responsibility has affected the land, as well as global warming. Environmental conditions changed by humans include climatic factors with respect to the land. One of the factors that affects bioclimatic factors is temperature. Good urban planning is required in order to establish comfortable ranges of temperature and humidity in the city, improving recreational areas, as well as accessibility to the land [24,25].

Phenological responses are strongly related to local climate conditions [5], such as temperature, precipitation, soil, drought, frost, latitude, biotic factor, etc. [15,26,27]. There are growth stages which categorize plant life cycles by unique features, such as budding, flowering, etc. and each stage requires different proper climate factors. The most influential factors on phenological events are temperature and precipitation [21].

However, current studies are either region-limited, sole-species, or suffer a short research period, so studies about various species are necessary throughout South Korea. A wide range of studies, adding more variables, are required because of the regional climate variety and phenological events which require physical and biological conditions in South Korea, even if most of studies just consider the increasing temperature. South Korea showed regional differences between urban and rural areas, inland and seaside and middle to southern areas, with increasing trends and frequent extreme events due to climate change from global warming. Urbanization studies for many different cities are demanded along with global warming. Temperature changes a great deal within the troposphere with altitude.

In this study, trends of change with respect to the budding and flowering dates of spring plants in South Korea are explored with respect to climate factors, such as temperature and precipitation, according to climate change and urbanization. Four species, such as *Forsythia koreana* (forsythia), *Rhododendron mucronulatum* (azalea), *Prunus yedoensis* (Yoshino cherry) and *Prunus mume* (Japanese apricot), are focused upon during the period from 1973 to 2008. The regional clusters of phenological responses are divided and the unique characteristics of each cluster are determined because the domestic climates showed different patterns due to the region's topographical features. Examination shows differences between the budding and flowering of plants, species and regions with respect to the degree by which climate factors affect them and, also, they are analyzed with respect to precipitation's impacts on them. The rural and urban areas, according to the global warming and urbanization effects, were compared with changing trends of phenological events. This study seeks to prove how much these phenomena are accelerated due to urbanization.

2. Data

2.1. Phenological Events and Stations

Meteorological observations in South Korea has been conducted at 84 stations, including North-Gangrueng, Gimhae, Soonchang, Changwon and Yangsan, which were newly-registered in 2008 since it started at Incheon in 1904 (data available from Korea Meteorological Administration, http://www.kma.go.kr/sfc/sfc_03_02.jsp). The Korean peninsula, located on Eurasian continent, of middle latitude in the northern hemisphere, extends southward from the northeastern part. Over 70% of the land is covered with mountains, thus, that the discrepancy in the climate is significantly larger than any other country (NIMR, 2004). The recent annual mean temperature and precipitation of South Korea showed increasing trends and frequent extreme events due to climate change caused by global warming. It also showed regional differences between urban and rural areas, inland and seaside areas and middle and southern areas in South Korea.

The Korea Meteorological Administration (KMA) [28] has been researching the phenological events with respect to phenomena of animals and plants for phenological change trends and climate change perception [29]. The observation has been done for plants for the budding, flowering and leaf color change of 10 species and for animals' first appearance date and last appearance date for nine species [29]. Budding and flowering data for a total of four plants—forsythia, azalea, Yoshino cherry and apricot—are used as the base materials. The collection of data of budding and flowering was done with a standardized process for each plant, where 20% of budding and flowering was processed. Each plant species was grown in the gardens of meteorological stations.

The 54 stations that contained continuous meteorological observation data from 1973 to 2008 have been chosen and the stations which have the missing data for three years in a row or 10 years during the entire research period have been disregarded (Figure 1). However, due to limitations in the availability of data, we were unable to study differences between plants (Table 1). The urban area is categorized as having populations over 1 million and the other areas are categorized as rural areas. Metropolitan cities (Seoul, Incheon, Daejeon, Daegu, Ulsan, Gwangju and Busan), including Suwon, are regarded as urban areas because they are regarded as metropolitan cities due to their population size and location.

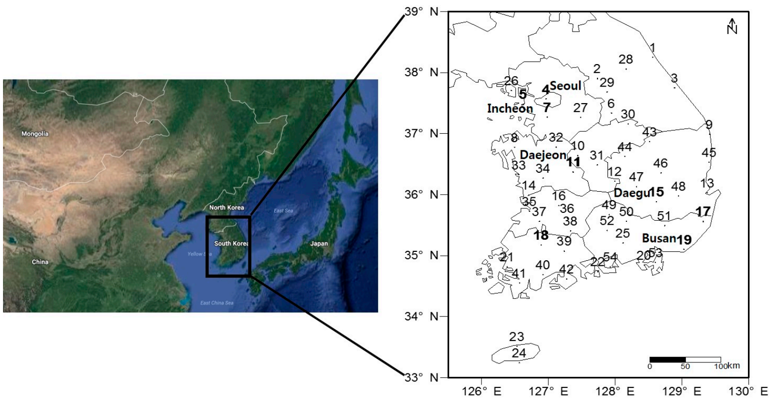

Figure 1. Map of South Korea showing the locations of the 54 stations. Bold numbers indicated chosen the urban areas. Over 1 million residents with Metropolitan cities were marked in the map.

Table 1. Locations of 54 stations and population information. Bold stations indicated chosen city as the urban areas. Species columns show phenological observation data. Event: budding (B), flowering (F).

No.	Station	Latitude [°N]	Longitude [°E]	Altitude [m]	Population [Thousands]	*Forsythia koreana*	*Rhododendron mucronulatum*	*Prunus yedoensis*	*Prunus mume*
1	Sokcho	38.25	128.56	23	86	B/F	B/F	B/F	B/F
2	Chuncheon	37.90	127.74	77	261	B/F	B/F	B/F	B/F
3	Gangneung	37.75	128.89	26	222	B/F	B/F	B/F	B/F
4	**Seoul**	37.57	126.97	86	10,421	B/F	B/F	B/F	B/F
5	**Incheon**	37.48	126.62	69	2710	B/F	B/F	B/F	B/F
6	Wonju	37.34	127.95	151	301	B/F	F	F	B/F
7	**Suwon**	37.27	126.99	35	1000	B/F	B/F	B/F	
8	Seosan	36.77	126.50	25	155	B/F	F	B/F	B/F
9	Uljin	36.99	129.41	49	54	F	F	B/F	
10	Cheongju	36.64	127.44	56	638	B/F	B/F	B/F	B/F
11	**Daejeon**	36.37	127.37	63	1487	B/F	B/F	B/F	
12	Chupungnyeong	36.22	127.99	241	3	B/F	B/F	B/F	B/F
13	Pohang	36.03	129.38	1	508	B/F	B/F	B/F	B/F
14	Gunsan	36.00	126.76	26	263	B/F	B/F	B/F	
15	**Daegu**	35.89	128.62	57	2513	F	F	B/F	F
16	Jeonju	35.82	127.15	61	628	B/F	B/F	B/F	B/F
17	**Ulsan**	35.56	129.32	35	1113	B/F	B/F	B/F	B/F
18	**Gwangju**	35.17	126.89	75	1423	B/F	B/F	B/F	B/F
19	**Busan**	35.10	129.03	69	3615	B/F	B/F	B/F	B/F
20	Tongyeong	34.85	128.44	31	134	B/F		B/F	
21	Mokpo	34.82	126.38	37	245	B/F	B/F	B/F	B/F
22	Yoesu	34.74	127.74	73	297	B/F	B/F	B/F	B/F
23	Jeju	33.51	126.53	20	408	B/F	B/F	B/F	B/F
24	Seogwipo	33.25	126.57	50	155	B/F	B/F	B/F	B/F
25	Jinju	35.16	128.04	27	333	B/F		B/F	B/F
26	Ganghwa	37.71	126.45	46	66	B/F	B/F	B/F	B/F
27	Icheon	37.26	127.48	90	198	F	B/F	B/F	
28	Inje	38.06	128.17	199	32	F		F	
29	Hongcheon	37.68	127.88	146	71	B/F	B/F	B/F	B/F
30	Jecheon	37.16	128.19	263	137	F	F	B/F	
31	Boeun	36.49	127.73	173	35	F	F	B/F	
32	Cheonan	36.78	127.12	21	540	F	F	F	
33	Boryeong	36.33	126.56	18	108	B/F	F	B/F	B/F
34	Buyeo	36.27	126.92	11	78	B/F	B/F	B/F	
35	Buan	35.73	126.72	4	62	F	F	F	
36	Imsil	35.61	127.29	248	32	B/F	B/F	B/F	
37	Jeongeup	35.56	126.87	40	125	F	F	F	F

Table 1. *Cont.*

No.	Station	Latitude [°N]	Longitude [°E]	Altitude [m]	Population [Thousands]	*Forsythia koreana*	*Rhododendron mucronulatum*	*Prunus yedoensis*	*Prunus mume*
38	Namwon	35.41	127.33	94	89	B/F	B/F	B/F	B/F
39	Suncheon	35.07	127.24	74	271	F	F	F	F
40	Jangheung	34.69	126.92	45	43	B/F	B/F	B/F	B/F
41	Haenam	34.55	126.57	5	83	B/F	B/F	B/F	B/F
42	Goheung	34.62	127.28	53	78	B/F	B/F	B/F	B/F
43	Yeongju	36.87	128.52	211	116	B/F		B/F	
44	Mungyeong	36.63	128.15	171	75	F	F	F	
45	Yeongdeok	36.53	129.41	41	43	B/F	B/F	B/F	
46	Uiseong	36.36	128.69	83	61	B/F	B/F	B/F	
47	Gumi	36.13	128.32	47	396	B/F	F	B/F	
48	Yeongcheon	35.98	128.95	93	107	B/F	B/F	B/F	B/F
49	Geochang	35.67	127.91	221	63	B/F		B/F	B
50	Hapcheon	35.57	128.17	33	55	B/F	B/F	B/F	B/F
51	Miryang	35.49	128.74	11	111	B/F	B/F	B/F	
52	Sancheong	35.41	127.88	139	35	B/F	B/F	B/F	B/F
53	Geoje	34.89	128.60	45	213	B/F	B/F	F	F
54	Namhae	34.82	127.93	43	51	F	F	F	F
		Total Budding Stations				42	35	45	30
		Total Flowering Stations				54	49	54	34

2.2. Climate Factors

This research focused on two shrub species, forsythia, azalea and two tree species, Yoshino cherry and apricot. Even if there are many environmental conditions affecting budding and flowering of these kinds of plants, the most influential factors are temperature and precipitation. These factors are much closer to our ordinary life and are easily measureable. Climate data which can be matched with phenological events include monthly mean, maximum and minimum temperatures and monthly average precipitation for each of the 54 meteorological stations. According to the research results, temperature, whether it is the mean [7], maximum, or minimum temperature [6], has a high correlation with phenological events. Consequently, many possibilities and South Korean climate characteristics, which are regionally diverse, can be deliberated and, so, this study considered various temperature variables, such as the mean, maximum and minimum. In accordance with climate change, there were some studies to prove the relation between vegetation greenness and evapotranspiration by satellite measurements, such as normalized difference vegetation index (NDVI) [30]. However, there has never been a study regarding the direct relationship between precipitation and phenological events in South Korea. Raw data was used instead of using annual moving averages even if deviation of precipitation was very large. The precipitation data which was used later can result from a summation of the daily data. Even though the first observation started in Apr 1904, at the Incheon meteorological observatory, the data from 1973 to 2008 can be used because there has been no missing data since 1973. In the case of temperature and precipitation, two months of data, which have the greatest impact, were used before phenological events [31].

3. Methods

3.1. Cluster Analysis

Statistically, the phenological events in South Korea are occurring in the following order: apricot budding → forsythia budding → azalea budding → apricot flowering → Yoshino cherry budding → forsythia flowering → azalea flowering → Yoshino cherry flowering. However, contour lines indicating the distribution of budding and flowering of each species show the timing differences of phenological events. In the case of apricot, especially, budding has a 34-day difference and flowering has a 42-day difference between Seoul (126.97° E, 37.57° N) and Jeju (126.53° E, 33.51° N). Due to these differences in South Korea, classifying several regions in phenological change research is required.

Cluster analysis recognizes each cluster's characteristics, by grouping a few clusters using similarities between observation values [32]. Similarity calculations of objects are by Euclidian distance. This is commonly used for the calculation of the distance between two positions using the right-angled triangle principal. The distance between given objects x and y in p dimensional space is as follows:

$$d(x,y) = \sqrt{\sum_{i=1}^{p}(x_i - y_i)^2}$$

The Ward method is a hierarchy cluster method that shows no duplications among clusters and reflects well the topographical characteristics of South Korea. Computing an average of all variables and measuring squared Euclidian distance between each cases and averages. Grouping the summation of squared Euclidian distances toward minimal means indicated an increasing trend. The final cluster can be decided by coefficients of agglomeration. Timing analysis of phenological events was decided by reflecting contour lines indicating the distribution and cluster analysis was performed by abstracting the high correlation factors from January to March. Yet, cluster analysis is not allowed to use many different unit variations; for instance, temperature (°C), precipitation (mm) and phenological events (day) units.

Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables [33]. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance that is observed in a much larger number of manifest variables. Factor analysis can also be used to generate hypotheses regarding causal mechanisms or to screen variables for subsequent analysis. Accordingly, factor analysis is used to find a common factor among many underlying variables and principle component analysis is generally used to extract common factors. The factors with Eigen values over 1 were rotated by the Varimax method. Varimax is an orthogonal rotation method that minimizes the number of variables that have high loadings on each factor. This method simplifies the interpretation of the factors. At this moment, the gained principal component score was regarded as the input variables for cluster analysis.

The clusters from one-way analysis of variance (ANOVA), which showed the discrepancies of phenological events, were confirmed [33]. The key point in ANOVA is that if there are no differences among the groups, then the between-groups variance and the within-groups variance will be approximately equal.

3.2. Multiple Linear Regression Model

The optimal regression model was applied among diverse temperature variables during the two months prior to the budding and flowering of each plant species per divided regional groups. Additionally, determining the ideal regression model that included the significant influence of precipitation, multiple linear regression attempts were necessary to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to the observed data [33]. Every value of the independent variable x is associated with a value of the dependent variable y:

$$Y' = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_p x_p$$

This equation predicts the phenological event. α is the constant, β is the coefficient and x is the predictor variable, such as temperature or precipitation in this study. When we calculate the multiple linear regression, we can obtain the R^2 value. The change in the R^2 statistic is produced by adding or deleting an independent variable. If the R^2 change associated with a variable is large, that means that the variable is a good predictor of the dependent variable.

3.3. Precipitation Effect

This study has expounded on either regions or phenological events that were significantly influenced by precipitation. When analysis elaborates, the precipitation characteristics, which have a large deviation different from temperature and can be contained under the ground for long periods, are applied. Accordingly, precipitation values are accumulated for five, 10, 15 and 30 days before phenological events occur. By doing so, it can be assumed that the minimum amount of precipitation for phenological events may occur.

3.4. Urbanization

The monthly fluctuation of climate factors and phenological events have been analyzed during the research period to prove the effect of global warming either overall or by each divided cluster. Urban areas are nominated to determine the intensity of the urbanization effect within the global warming effect. The urban area is categorized with populations greater than 1 million (metropolitan cities based on the Ministry of Administration in Korea) and the other areas are categorized as rural areas. Defining the phenological events and the change of climate factors, through the same method as global warming, proves the urbanization effect by analyzing the difference between global warming and urbanization. Lastly, the gap will be defined by comparing the change rate of phenological events from each city.

4. Results

4.1. Cluster Analysis According to Phenological Events and Climates

During the early spring (January to March) period from 1973 to 2008, phenological events and climate factors showed significant correlation through the entirety of South Korea (Table 2). The mean temperature of February and March showed high significant correlation even if temperature variables had a significant correlation on all mean, maximum and minimum temperatures. The phenological events of these three species (forsythia, azalea and Yoshino cherry) were similar during this period and the factor was abstracted from the mean temperature in both February and March and precipitation in February. Since apricot is the first budding plant among the four species, the mean temperature factor in both January and February and precipitation factor in February, were abstracted. For flowering, factors were abstracted from the mean temperature in both January and February and precipitation in March. It has shown similarities among budding and flowering of forsythia, azalea, Yoshino cherry and apricot, as well as flowering of apricot (Figure 2). Two clusters were divided; one was on east and south coast area and the other one on the west coast and inland area. The clusters of flowering of the three species were divided into three clusters. Apricot budding was divided into two groups, the east coast area including Jeju Island and other areas even if analyzable stations only numbered 30 out of 54. The results of these clusters are that phenological events have been fairly influenced by climate factors. This is because the result of the clusters, which only considered climate factors, excluded phenological events' variables and appeared to be almost identical (Figure 3). Finally, budding of forsythia, azalea and Yoshino cherry and flowering of apricot, are defined as Type I and the flowering of forsythia, azalea and Yoshino cherry were grouped as Type II. Apricot budding was different from the others, so it was defined as Type III (Figure 4). Phenological events among clusters by ANOVA analysis had significant differences (Table 3).

Table 2. Correlation coefficient between phenological events and climate factors. Bold coefficients are the abstracted factors for factor analysis.

		Mean Temperature			Maximum Temperature			Minimum Temperature			Precipitation		
		January	**February**	**March**	**January**	**February**	**March**	**January**	**February**	**March**	**January**	**February**	**March**
Forsythia koreana	Budding	−0.614 **	**−0.719** **	**−0.732** **	−0.580 **	−0.675 **	−0.557 **	−0.594 **	−0.660 **	−0.655 **	−0.249 **	**−0.329** **	−0.265 **
	Flowering	−0.631 **	**−0.741** **	**−0.792** **	−0.605 **	−0.712 **	−0.668 **	−0.626 **	−0.691 **	−0.706 **	−0.275 **	**−0.337** **	−0.217 **
Rhododendron mucronulatum	B	−0.589 **	**−0.670** **	**−0.667** **	−0.564 **	−0.629 **	−0.503 **	−0.568 **	−0.616 **	−0.605 **	−0.258 **	**−0.265** **	−0.258**
	F	−0.574 **	**−0.667** **	**−0.675** **	−0.558 **	−0.644 **	−0.557 **	−0.625 **	−0.611 **	−0.532 **	−0.310 **	**−0.293** **	−0.178 **
Prunus yedoensis	B	−0.606 **	**−0.676** **	**−0.698** **	−0.578 **	−0.633 **	−0.550 **	−0.580 **	−0.619 **	−0.617 **	−0.263 **	**−0.268** **	−0.238 **
	F	−0.654 **	**−0.757** **	**−0.808** **	−0.649 **	−0.755 **	−0.723 **	−0.634 **	−0.687 **	−0.686 **	−0.322 **	**−0.305** **	−0.208 **
Prunus mume	B	**−0.710** **	**−0.713** **	−0.708 **	−0.676 **	−0.649 **	−0.510 **	−0.681 **	−0.668 **	−0.650 **	−0.244 **	**−0.264** **	−0.310 **
	F	−0.687 **	**−0.710** **	**−0.705** **	−0.687 **	−0.687 **	−0.567 **	−0.654 **	−0.647 **	−0.623 **	−0.242 **	−0.275 **	**−0.293** **

** Significant at the 0.001 level.

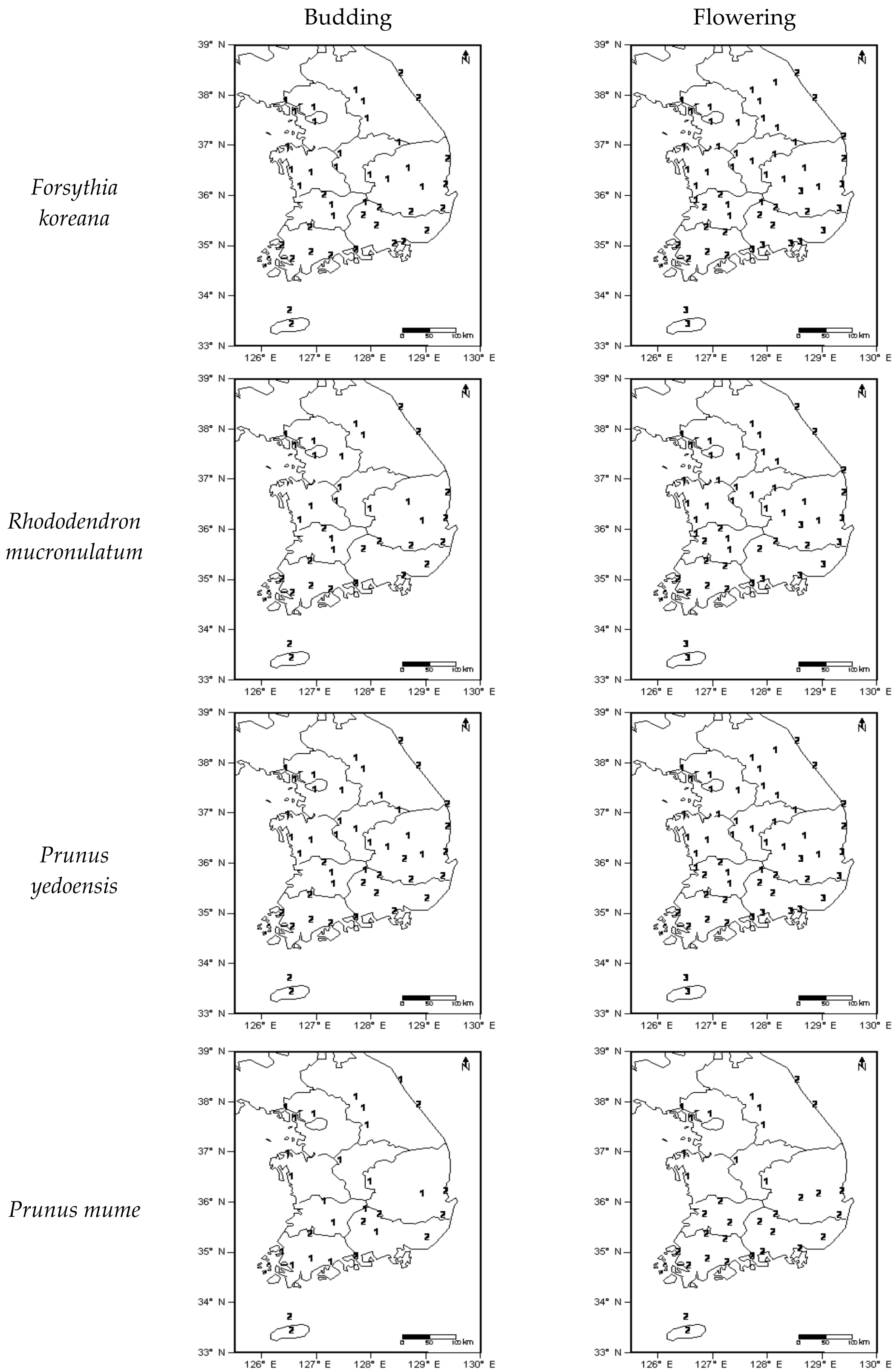

Figure 2. Cluster analysis that are considering with phenological events and climate factors which are the abstracted factors for factor analysis.

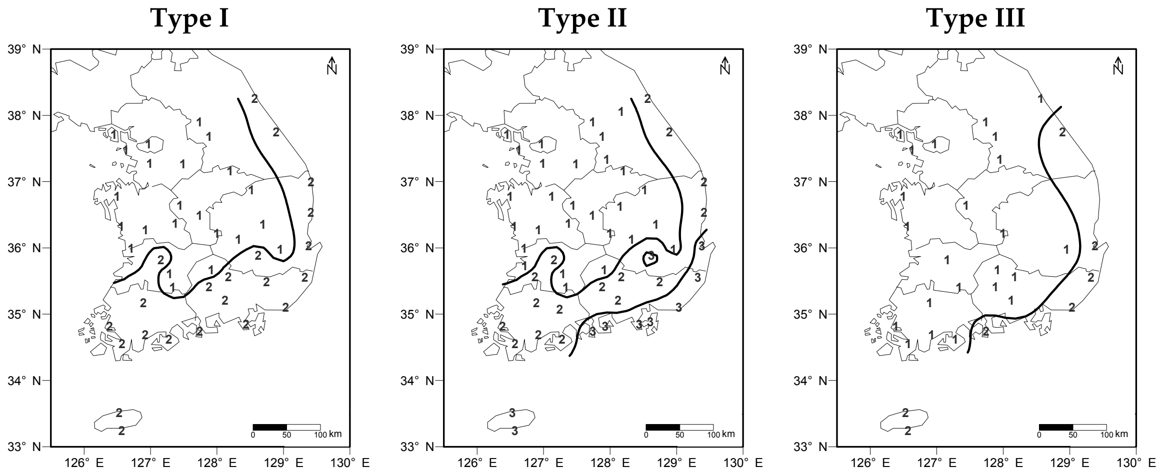

Figure 3. Cluster analysis that are considering with phenological events except climate factor. Numbers of 1, 2 and 3 on each station mean same group.

Table 3. ANOVA analysis of phenological events between clusters. All clusters on each species showed the non-homogeneous.

			SS	df	MS	F	*p*
Fosythia koreana	Budding	Between Groups	28,917	1	28,917	506	0.000
		Within Groups	83,479	1460	57		
		Total	112,396	1461			
	Flowering	Between Groups	42,544	2	21,272	500	0.000
		Within Groups	81,082	1906	43		
		Total	123,626	1908			
Rhododendron mucronulatum	B	Between Groups	29,234	1	29,234	371	0.000
		Within Groups	94,593	1202	79		
		Total	123,827	1203			
	F	Between Groups	35,891	2	17,945	332	0.000
		Within Groups	92,371	1709	54		
		Total	128,262	1711			
Prunus yedoensis	B	Between Groups	38,414	1	38,414	555	0.000
		Within Groups	107,311	1551	69		
		Total	145,725	1552			
	F	Between Groups	35,356	2	17,678	481	0.000
		Within Groups	69,679	1896	37		
		Total	105,035	1898			
Prunus mume	B	Between Groups	93,729	1	93,729	360	0.000
		Within Groups	265,764	1021	260		
		Total	359,493	1022			
	F	Between Groups	155,840	1	155,840	669	0.000
		Within Groups	269,931	1159	233		
		Total	425,770	1160			

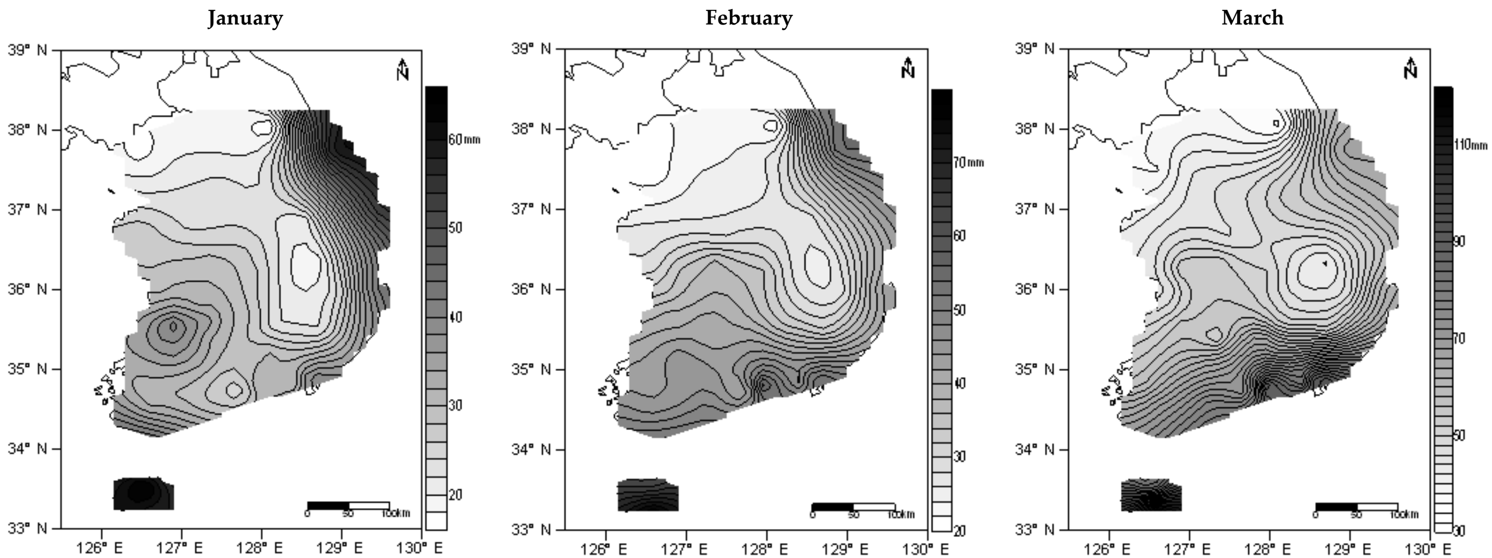

Figure 4. Finalized clusters of each type. Type I: Budding of *Forsythia koreana*, *Rhododendron mucronulatum* and *Prunus yedoensis* and flowering of *Prunus mume*. Type II: Flowering of *Forsythia koreana*, *Rhododendron mucronulatum* and *Prunus yedoensis*. Type III: Budding of *Prunus mume*. Numbers of 1, 2 and 3 on each station mean same group. Number 1 is inland area including west coast, 2 and 3 are coast areas. Number 3 area is a subtropical climate.

4.2. Phenological Responses to Temperature and Precipitation

Temperature variables are the only significant impact factor for all budding plants. The mean temperatures in February and March had high influences on the budding of forsythia, azalea and Yoshino cherry in Cluster 1 of Type I (Table 4). The mean temperature in March showed a higher influence than that of February, whereas precipitation did not have a significant impact. The mean and maximum temperature in February showed the highest influences on the budding of forsythia and Yoshino cherry, while azalea showed a slightly different impact on Cluster 2. Precipitation did not have any significant impact on Cluster 1. In the case of apricot, the largest and most significant impact on Cluster 1 was the January mean temperature and February maximum temperature and the minimum temperatures in January and February for Cluster 2 of Type III. Precipitation, which had a smaller impact than temperature in Cluster 1 of Type II, had significant impact on forsythia, azalea and Yoshino cherry (Table 5). The maximum temperature in February, the mean temperature in March and the precipitation in February and March showed a significant impact on the flowering of forsythia and Yoshino cherry, while azalea showed a slightly different impact. Significant impacts on Clusters 2 and 3 were not the precipitation but the temperature, variables. The flowering of apricot was Type I and precipitation had a significant impact on Cluster 1. This region was the same as Cluster 1 of Type II and was similar to other phenological events; the mean temperature in March, the maximum temperature in February and the precipitation in March had significant impacts. Apricot flowering occurred very early in Cluster 2 and the mean temperature in January and the maximum temperature in February had significant impacts but precipitation did not.

Table 4. The best adequate models evaluated in the multiple linear analysis of each species budding. Temperature and precipitation of Mean, Max and Min were used during January, February and March R_2 = Coefficient of determination.

Type	Cluster	*Forsythia koreana*	*Rhododendron mucronulatum*	*Prunus yedoensis*	*Prunus mume*
I	1	Phenology = 93.21 − 1.23 × FMT − 2.66 × MMT (R_2 = 0.507)	Phenology = 94.76 − 1.50 × FMT − 2.43 × MNT (R_2 = 0.507)	Phenology = 98.85 − 1.06 × FMT − 2.35 × MMT (R_2 = 0.337)	
	2	Phenology = 83.42 − 1.28 × FMT − 0.97 × FXT (R_2 = 0.358)	Phenology = 91.319 − 0.43 × JMT − 2.12 × FXT (R_2 = 0.307)	Phenology = 92.20 − 1.05 × FMT − 1.39 × FXT (R_2 = 0.338)	
III	1				Phenology = 84.72 − 2.62 × JMT − 2.49 × FXT (R_2 = 0.331)
	2				Phenology = 49.695 − 1.35 × JNT − 1.22 × FNT (R_2 = 0.313)

Note: JMT = January Mean Temperature, FMT = February Mean Temperature, MMT = March Mean Temperature, JXT = January Max Temperature, FXT = February Max Temperature, MXT = March Max Temperature, JNT = January Min Temperature, FNT = February Min Temperature, MNT = March Min Temperature.

Table 5. The best adequate models evaluated in the multiple linear analysis of each species flowering. Temperature and precipitation of Mean, Max and Min were used during January, February and March.

Type	Cluster	*Forsythia koreana*	*Rhododendron mucronulatum*	*Prunus yedoensis*	*Prunus mume*
I	1				Phenology = 124.84 − 3.60 × MMT − 2.32 × FXT + 0.04 × MMP (R_2 = 0.435)
	2				Phenology = 98.18 − 2.04 × JNT − 2.81 × FXT (R_2 = 0.331)
II	1	Phenology = 109.55 − 3.09 × MMT − 0.62 × FXT − 0.02 × FMP + 0.01 × MMP (R_2 = 0.574)	Phenology = 101.64 − 2.60 × MMT − 0.81 × FNT + 0.02 × MMP (R_2 = 0.472)	Phenology = 116.09 − 2.36 × MMT − 0.90 × FXT + 0.02 × MMP (R_2 = 0.550)	
	2	Phenology = 107.39 − 0.40 × FMT − 0.39 × MXT (R_2 = 0.423)	Phenology = 101.43 − 1.74 × FMT − 1.81 × MMT (R_2 = 0.435)	Phenology = 120.81 − 1.47 × FMT − 1.86 × MXT (R_2 = 0.573)	
	3	Phenology = 94.22 − 0.68 × FMT − 1.36 × FXT (R_2 = 0.398)	Phenology = 113.17 + 2.17 × FMT − 4.40 × FXT (R_2 = 0.222)	Phenology = 126.77 − 1.39 × FMT − 2.39 × MXT (R_2 = 0.649)	

Note: JMT = January Mean Temperature, FMT = February Mean Temperature, MMT = March Mean Temperature, JXT = January Max Temperature, FXT = February Max Temperature, MXT = March Max Temperature, JNT = January Min Temperature, FNT = February Min Temperature, MNT = March Min Temperature, JMP = January Mean Precipitation, FMP = February Mean Precipitation, MMP = March Mean Precipitation.

4.3. Details of Precipitation Effect

Precision analysis was conducted for Cluster 1 of type II, showing positively- or negatively-significant correlations between average precipitation and flowering timing (Table 6). This area is drier than other areas in early spring (Figure 5). The precipitation showed clear characteristics by region per month. It had been concentrated in the east in January and on the south coast and Jeju Island in February and March, whereas it had less correlation than temperatures. Therefore, details of precipitation's effect were studied in Cluster 1 of Type II, which divided regions with respect to flowering. Flowering of forsythia, azalea and Yoshino cherry tree occurred, on average, about 10 days after budding in this region and 15 days for apricot. The results of the post hoc range by the Scheffe test after ANOVA, per plant species, with precipitation accumulation of five days, 10 days, 15 days and 30 days prior to flowering, showed a similar trend of precipitation's accumulation between forsythia and azalea (Table 6). Mean precipitation of each month did not contribute significantly because the deviation of precipitation seemed so large. Therefore, the accumulation of precipitation was eligible for flowering in 10–90% of Cluster 1 (Table 7). An accumulation of precipitation in most regions during the five days before flowering is zero. This is why we need to check the accumulation of over five days prior to flowering. If the accumulation was over 1 mm in the 10 days ahead, or if the accumulation was over 5 mm in 15 the days ahead, forsythia and azalea would flower in 80% of region. In the case of trees, it seemed that more precipitation was required than for shrubs. If the accumulation was over 2 mm and 6 mm in 10 days and 15 days prior, Yoshino cherry flowering occurred in 80% of the region. Budding and flowering normally showed 10 deviations and it was proper to check the accumulation of precipitation 10 days ahead. If precipitation was over 7 mm in the 15 days prior to flowering for apricot, it flowered in 80% of the region (Figure 6).

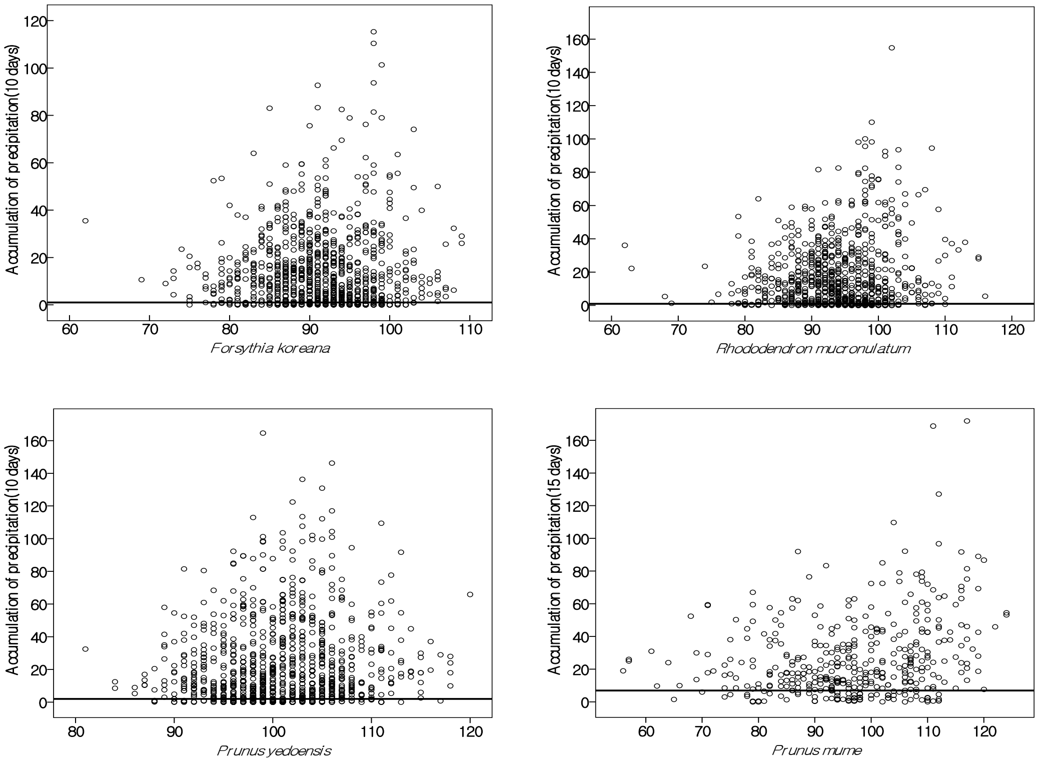

Figure 5. Contour lines indicated the distribution of January to March precipitation during 1973–2008. x-axis means Julian days.

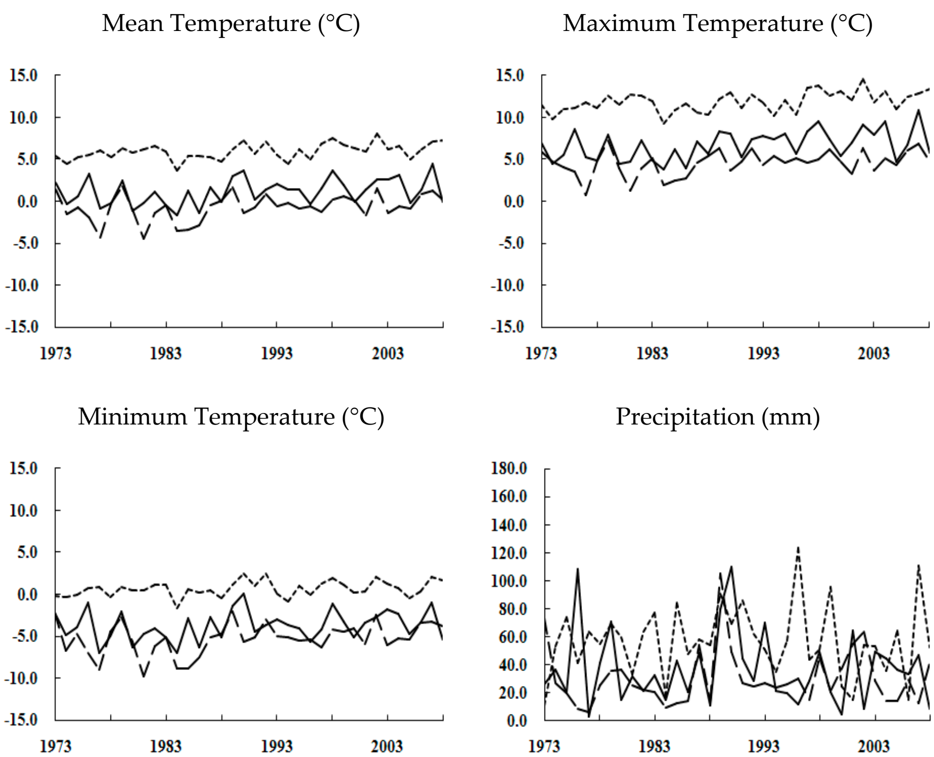

Figure 6. Reference lines: requirements for over 80% flowering in cluster 1 of Type II. *Forsythia koreana* and *Rhododendron mucronulatum*: 1 mm of 10 days, *Prunus yedoensis* tree: 2 mm of 10 days and *Prunus mume*: 7 mm of 15 days before flowering. x-axis means year and y-axis means temperature.

Table 6. Descriptive statistics of Precipitation accumulation and ANOVA analysis between species. *Forsythia koreana* and *Rhododendron mucronulatum* are homogeneous subsets by Scheffe.

		N	Mean	SD	ANOVA	SS	df	MS	F	*p*
5 days	*Forythia koreana*	985	7.7	13.2	Between Groups	11,154	3	3718	15	0.000
	Rhododendron mucronulatum	869	9.6	13.1						
	Prunus yedoensis	978	12.4	19	Within Groups	824,765	3235	254		
	Prunus mume	407	9.1	13.8						
					Total	835,919	3238			
10 days	*Forythia koreana*	985	14.4	16.5	Between Groups	11,154	3	3718	27	0.000
	Rhododendron mucronulatum	869	17.1	20.1						
	Prunus yedoensis	978	22.8	25.6	Within Groups	824,765	3235	254		
	Prunus mume	407	18.3	19.6						
					Total	835,919	3238			
15 days	*Forythia koreana*	985	21.4	19.1	Between Groups	11,154	3	3718	29	0.000
	Rhododendron mucronulatum	869	24.2	23.6						
	Prunus yedoensis	978	31.3	29.8	Within Groups	824,765	3235	254		
	Prunus mume	407	26.9	24.6						
					Total	835,919	3238			
30 days	*Forythia koreana*	985	44.3	27	Between Groups	11,154	3	3718	9	0.000
	Rhododendron mucronulatum	869	45.5	29.4						
	Prunus yedoensis	978	51.1	35.6	Within Groups	824,765	3235	254		
	Prunus mume	407	48.9	36.2						
					Total	835,919	3238			

Table 7. Precipitation accumulation (mm) of the 5 days, 10 days, 15 days and 30 days before flowering.

Flowering	***Forsythia koreana***				***Rhododendron mucronulatum***				***Prunus yedoensis***				***Prunus mume***			
Events (%)	**5 Days**	**10 Days**	**15 Days**	**30 Days**	**5 Days**	**10 Days**	**15 Days**	**30 Days**	**5 Days**	**10 Days**	**15 Days**	**30 Days**	**5 Days**	**10 Days**	**15 Days**	**30 Days**
90%	0	0	2.4	13.6	0	0	1.9	13	0	0.2	2.7	13	0	0.2	2.5	11.6
80%	0	1	5.7	21.3	0	1.1	4.9	21	0	2.1	6.4	20.8	0	1.7	7.4	18.9
70%	0	2.9	9.5	27.5	0	2.9	9.5	27.5	0.1	5	11.5	27.1	0	5	11.3	25.2
60%	0.5	6	13.3	32.5	0.5	6.4	13.5	32	1.2	9	16.5	34	0.7	9.2	15	31.3
50%	1.5	9.6	16.5	38.7	2	10.5	17.3	39.1	3.2	13	22.5	42.4	2.5	12.6	19.7	39.7
40%	4.3	13.5	20.5	45.8	5.1	14.6	22.6	47.2	7.2	19.5	30	52.8	5.5	15.2	25.5	50
30%	8	17.9	25.6	54.8	9.8	21.5	29.4	56.8	12.5	28.4	38.5	65	10.2	20.9	34	60.7
20%	13	25	33.5	65.3	15.3	30	39	68.9	22.5	40.2	52	76.9	16.1	31.4	44.2	72
10%	22.9	35.2	47	84.5	30.1	44.5	53.5	85.4	39.3	58.6	71	100.6	29.1	46.5	59.5	97.5

4.4. Global Warming and Urbanization

The mean temperature has increased by about 1.6 °C, the maximum temperature by about 1.8 °C and the minimum temperature by about 1.4 °C. Precipitation also increased by about 18.8 mm during the past 35 years (Figure 7). The increasing rate is highest with respect to the maximum temperature in February and the minimum temperature in March, with the regions of Cluster 2 of Type I and Cluster 3 of Type II having impressive increasing ratios (Table 8). Precipitation is either increasing or decreasing per region; this showed no statistically significant results. Phenological events are advancing along with increasing temperature. During this period, there were advancements of 3.1 days of forsythia (budding 3.3 days, flowering 2.9 days), 5.5 days of azalea (budding 6.6 days, flowering 4.5 days), 6.5 days of Yoshino cherry (budding 5.6 days, flowering 7.2 days) and 18.6 days of apricot (budding 17.9 days, flowering 19.4 days) (Figure 8). The decreasing ratio of tree phenological events showed a higher slope than shrubs. Budding of shrubs is getting faster than their flowering and the flowering of trees are faster than their budding (Table 9).

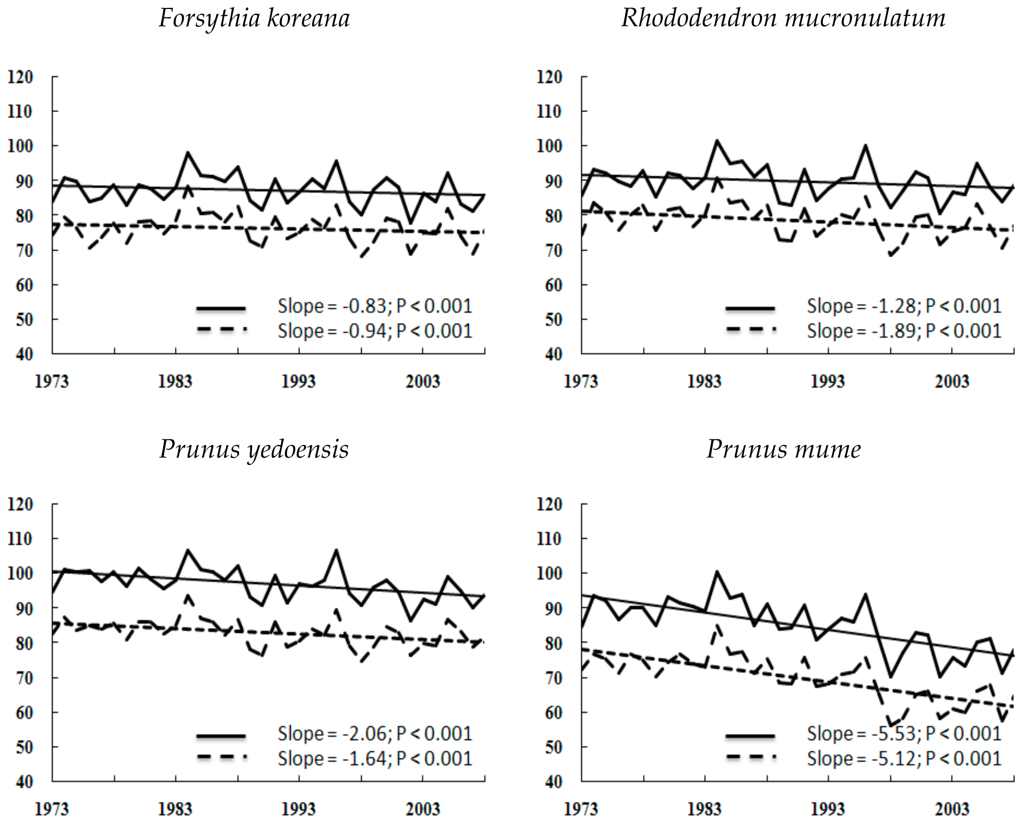

Figure 7. Overall temperature and precipitation changes from 1973 to 2008 in South Korea. January (– – –), February (— —) and March (- - - -).

Table 8. Regression coefficients of climate factors in divided regions per type during 1973–2008. Temperature factors showed significance whereas precipitation showed limited significance.

		Mean Temperature			**Maximum Temperature**			**Minimum Temperature**			**Precipitation**		
		January	**February**	**March**	**January**	**February**	**March**	**January**	**February**	**March**	**January**	**February**	**March**
All stations		0.48 **	0.46 **	0.40 **	0.45 **	0.69 **	0.51 **	0.57 **	0.33 **	0.29 **	0.57	0.43 *	1.42
Type I	Cluster 1	0.55 **	0.46 **	0.42 **	0.51 **	0.73 **	0.52 **	0.64 **	0.32 **	0.27 **	0.33	0.72	−0.29
	Cluster 2	0.43 **	0.48 **	0.39 **	0.40 **	0.65 **	0.50 **	0.50 **	0.36 **	0.32 **	0.16	−3.36 *	2.15
Type II	Cluster 1	0.55 **	0.46**	0.42 **	0.51 **	0.73 **	0.52 **	0.64 **	0.32 **	0.27 **	0.33	0.72	−0.29
	Cluster 2	0.29 **	0.35 **	0.33 **	0.34 **	0.63 **	0.50**	0.29 **	0.16 *	0.18 **	−0.13	−4.50 *	1.95
	Cluster 3	0.53 **	0.57 **	0.45 **	0.42 **	0.62 **	0.46 **	0.68 **	0.56 **	0.50 **	2.58	−1.88	2.58
Type III	Cluster 1	0.48 **	0.43 **	0.39 **	0.48 **	0.71 **	0.52 **	0.55 **	0.27 *	0.24 **	0.41	−1.61 *	0.71
	Cluster 2	0.49 **	0.58 **	0.45 **	0.37 **	0.62 *	0.48 **	0.63 **	0.56 **	0.47 **	2.81	−3.44	1.46

* Significant at the 0.05 level. ** Significant at the 0.001 level.

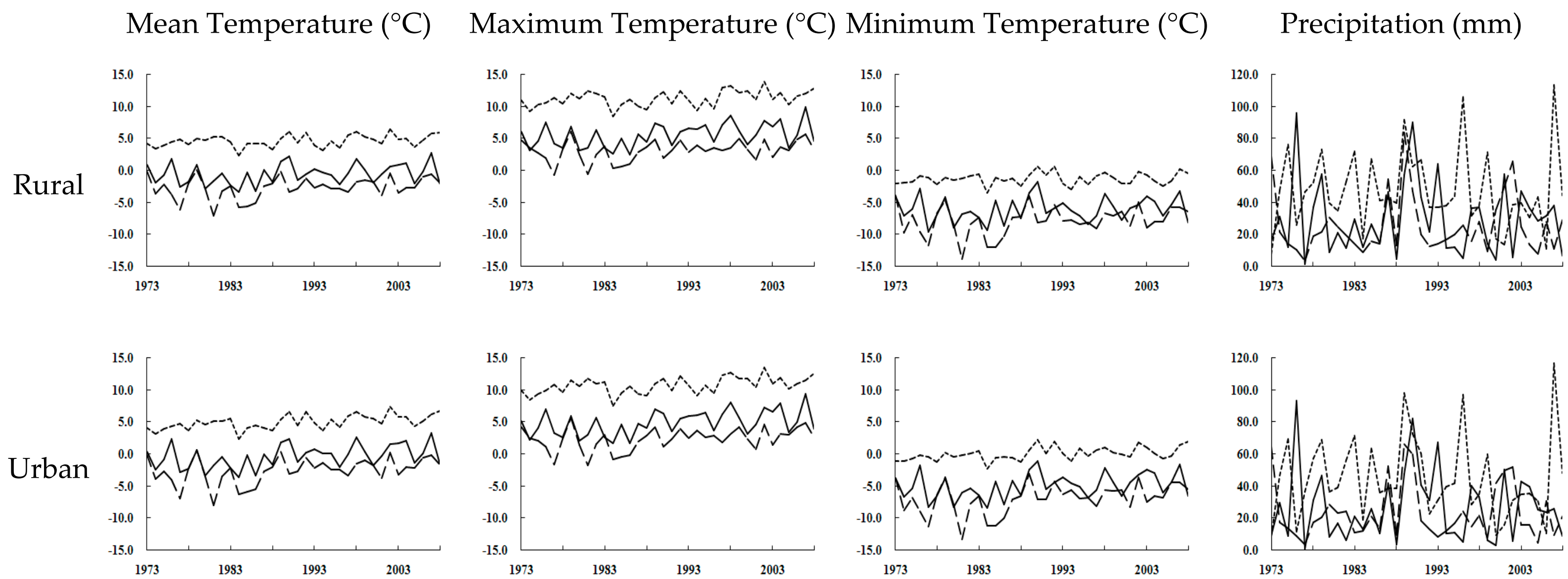

Figure 8. Trends of phenological changes for study species in South Korea. Flowering (— —) and budding (- - - - -).

Table 9. Regression coefficients of each species' phenological changes of budding and flowering in divided regions per type during 1973–2008.

		Forsythia koreana		*Rhododendron mucronulatum*		*Prunus yedoensis*		*Prunus mume*	
		Budding	**Flowering**	**B**	**F**	**B**	**F**	**B**	**F**
All stations		−0.94 **	−0.83 **	−1.89 **	−1.28 **	−1.64 **	−2.06 **	−5.12 **	−5.53 **
Type I	Cluster 1	−0.86 **		−1.59 **		−1.65 **			−5.50 **
	Cluster 2	−1.05 **		−2.16 **		−1.82 **			−5.66 **
Type II	Cluster 1		−0.90 **		−1.34 **		−1.55 **		
	Cluster 2		−0.69 **		−0.67 **		−1.59 **		
	Cluster 3		−1.06 **		−2.24 **		−2.51 **		
Type III	Cluster 1							−4.98 **	
	Cluster 2							−5.67 **	

** Significant at the 0.001 level.

The regions of Cluster 2 of Type I and Cluster 3 of Type II showed that the phenological changes are remarkable, as are temperature changes. Metropolitan cities (Seoul, Incheon, Daejeon, Daegu, Ulsan, Gwangju and Busan) including Suwon, showed more clear changes of climate and phenological events than rural areas. During this period, rural areas showed the increase on mean temperature of about 1.5 °C and maximum temperature of about 1.9 °C, a minimum temperature of about 1.2 °C and precipitation of about 9.4 mm. On the contrary, urban areas showed that the mean temperature increased about 2.0 °C and precipitation by about 0.3 mm (Figure 9). The temperature change ratio of urban areas is higher and significant (Table 10). Precipitation in both rural and urban areas in February have a decreasing trend and it is not significant. Phenological events in urban areas have advanced about 3–4 days compared to rural areas. There were advancements of about 2.3 days of forsythia, 4.3 days of azalea, 5.6 days of Yoshino cherry and 16.2 days of apricot in rural areas. Similarly, there were advancements of about 5.1 days for forsythia, 7.5 days for azalea, 9.5 days for Yoshino cherry and 20.2 days for apricot in urban areas (Figure 10). Apricot showed statistically significant changes without any relation to regions. The other plants in urban areas showed significant changes (Table 10). There are many insignificant cases in rural areas, whereas the urban areas are significant. The phenological event change ratio in Clusters 2 and 3 of Type II was the evidence. This region is the same as Cluster 2 of Type I; however, the change ratio in Cluster 3 of Type II is very large, so it led the overall changes in Clusters 2 and 3 of Type II. Additionally, over 30% of this region is urban, helping to support the results.

Each city had the differences in phenological events. Shrubs in Seoul, Incheon, Ulsan and Busan sometimes showed positive correlations (Figure 11). The most vivid phenological event is forsythia in Gwangju. Budding and flowering of shrubs showed slightly significant advanced trends. In particular, there were very large phenological events of apricot in Seoul and Daegu, a region that is basin-shaped and has serious urbanization effects.

Table 10. Regression coefficients of climate factors between rural and city areas during 1973–2008.

			Mean Temperature			Maximum Temperature			Minimum Temperature			Precipitation		
			January	February	March	January	February	March	January	February	March	January	February	March
All stations		Rural	0.45	0.43	0.37 *	0.44	0.68 *	0.51 *	0.53	0.29	0.25	1.01	−2.25	0.93
		Urban	0.70 *	0.72 *	0.58 **	0.53 *	0.75 **	0.54 *	0.81 *	0.65 *	0.57 **	0.42	−0.77	0.57
Type I	Cluster 1	R	0.45	0.35	0.31 *	0.46	0.68 *	0.46 *	0.54	0.20	0.16	0.48	−0.85	−0.32
		U	0.78 *	0.77 *	0.64 **	0.57	0.78 *	0.54 *	0.87 *	0.69 *	0.62 **	0.14	−0.59	0.00
	Cluster 2	R	0.37	0.44	0.36 *	0.37	0.65 *	0.50 *	0.44	0.31	0.27	1.57	−3.8	2.47
		U	0.62 *	0.67 *	0.53 **	0.50 *	0.72 *	0.54 *	0.75 *	0.61 *	0.52 **	0.71	−0.94	1.15

* Significant at the 0.05 level, ** Significant at the 0.001 level.

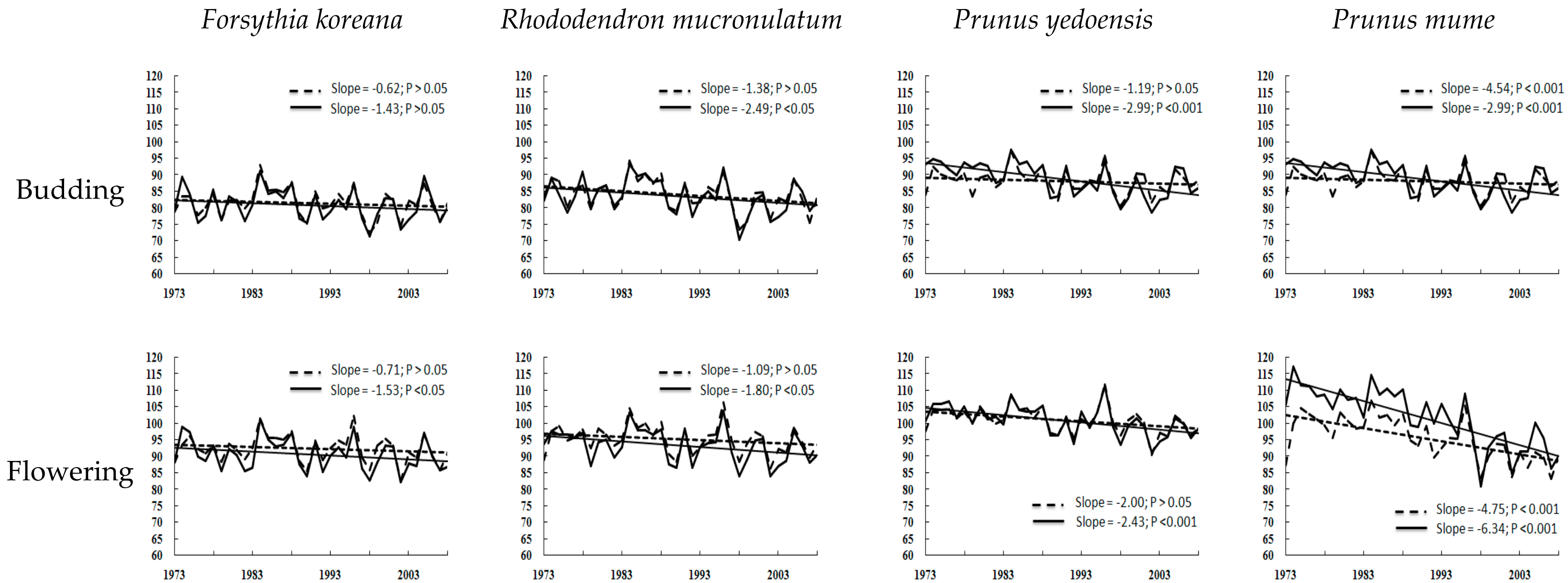

Figure 9. Comparison the changes of temperature and precipitation between rural and urban areas. January (– – –), February (— —) and March (- - - - -).

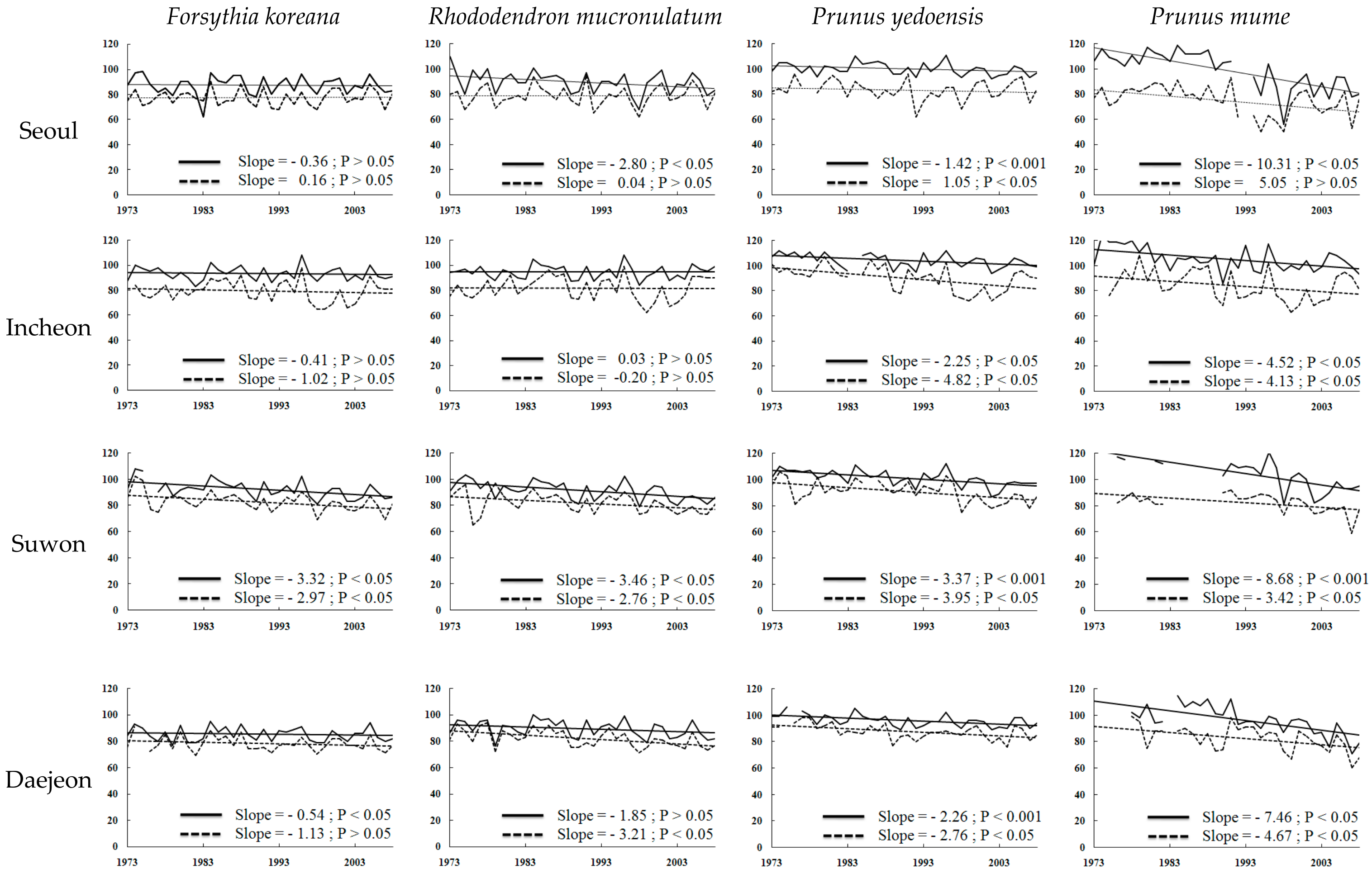

Figure 10. Comparison the trends of phenological changes both rural and city areas for study species in South Korea. Urban areas (— —) and Rural areas (- - - - -).

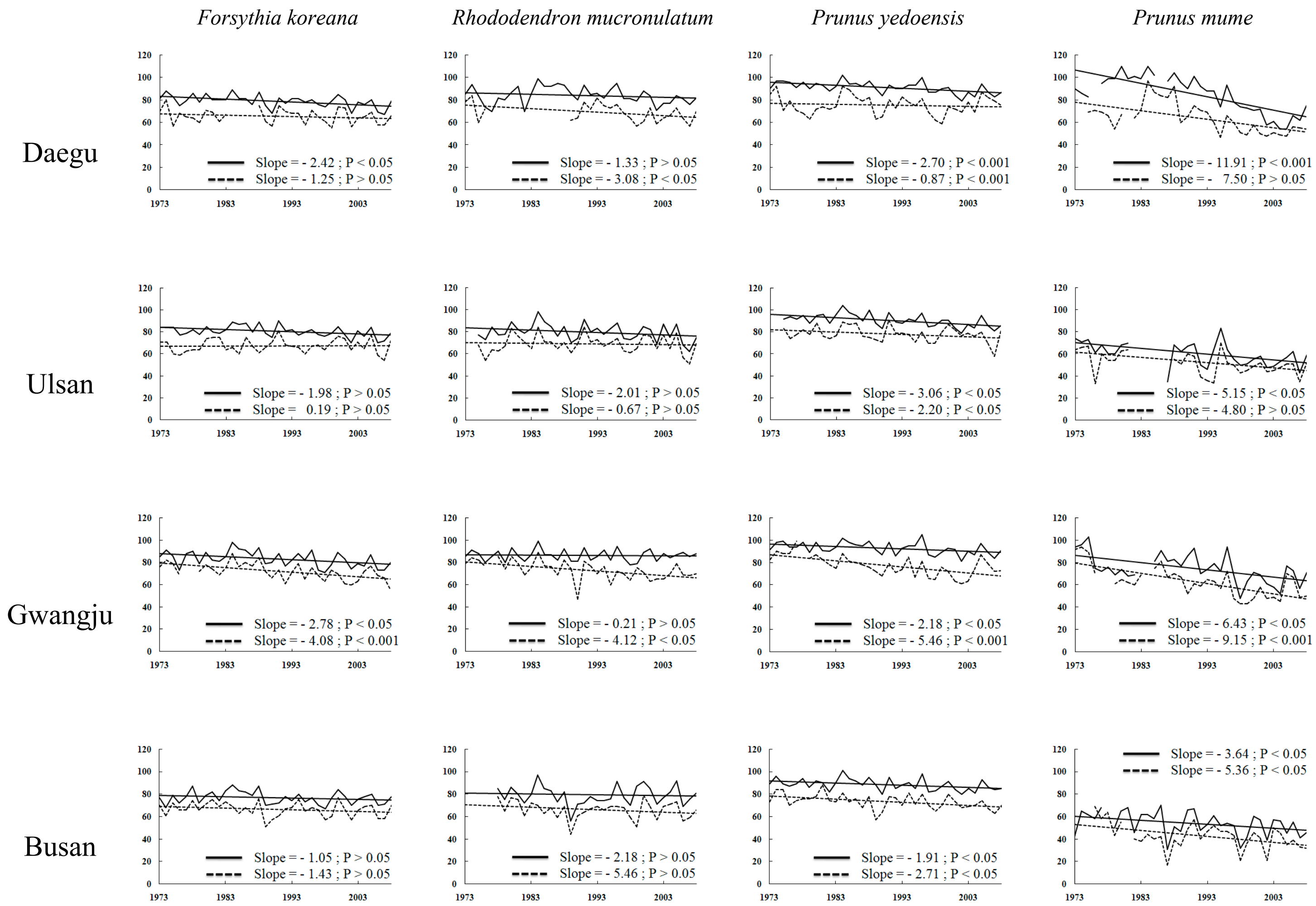

Figure 11. Comparison of budding and flowering trends in metropolitan cities and Suwon. Flowering (— —) and budding (- - - - -).

5. Discussion

Current studies are either region-limited, sole-species, or suffer short research periods, so studies about various species are necessary throughout South Korea. Before studying the phenological responses in South Korea, regions are divided because of the varying regional climate. Cluster analysis that categorized the domestic regions in spring with climate factors and phenological events, defined the local characteristics. The performed cluster analysis has similar outputs compared with region classification by using only climate factors [34]. This explains that phenological events have been seriously affected by climate. There are no differences between Type I and 2. The Cluster 1 region is a cold and dry area that is affected by the Siberian high atmospheric pressure. On the other hand, Clusters 2 and 3 are humid and warm coastal areas, even in the winter season, due to the southeastern wind [35]. Additionally, Cluster 1 and Cluster 2 and 3 regions can be divided by a large domestic mountain range (Figure 12). This resembles a reverse L-shape (┘). Climates are influenced by latitude and also by topographical factors ([35]. Ganghwa (37.71° N 126.45° E) and Gangnueng (37.75° N 128.89° E) are placed at similar latitudes and the rural areas around the coastline but these are divided as different clusters because of the unique topography (high east, low west-type) of South Korea. Apricot budding, which is of type III, can be largely affected in January and February by the Siberian high atmospheric pressure.

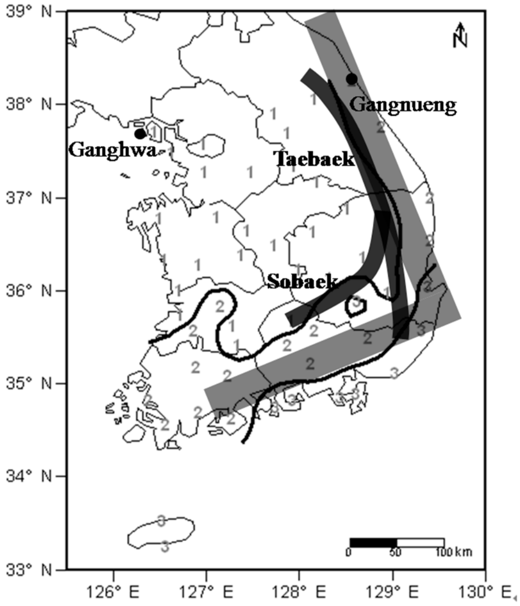

Figure 12. Map of domestic huge mountain range (⅄) which are Taebaek and Sobaek. Divided region resembled as reversed L-shape (┘).

Budding events of every plant can only be influenced by temperature variables. Flowering events in Cluster 1 of Type II are significantly affected by precipitation. It is very difficult to judge the correlation between precipitation and phenological events because of the scattered trend of precipitation during the study period. There are seasonal differences of precipitation in spring and winter and a small amount of precipitation was found. Fifty to sixty percent of average yearly precipitation is in summer (according to the KMA). Additionally, there are regional differences. Cluster 1 regions of Type II are drier than Cluster 2 and 3 in early spring, which is drier than any other seasons. The proper precipitation is able to exert an effect on flowering rather than the region that is rich in precipitation. Plants need just a small amount of precipitation to initiate the flowering, even though it seems that trees required more precipitation than shrubs. The inference is that the phenological events, however, sensitively reacted to precipitation, as this region is an especially dry area. Definitely, the impact of precipitation is much less than the impact of temperature [36]. Temperature is the one of the confident factors to explain the phenological events in South Korea. The enlargement of the value, at least with respect to significant precipitation variability, would help to minimize the error or the deviation on the prediction of phenological events. Then, if the temperature changed according to the altitude, the precipitation documents are easily applicable to the phenological observations.

Additionally, flowering can show the climate factor effect better than budding events. This can be considered as an error during the process of phenological data collection. The observations were conducted by agency employees according to sampling protocols [29]. They observed the date that budding occurred in approximately 20% of all buds on each species and when some of the flowers fully-bloomed, it was declared the flowering date [29]. However, there were differences in every single criterion and the view from each individual at each station may introduce many errors due to the surroundings of the observed stations [37]. These phenological events are becoming influenced by their surroundings so much that the error could be caused by the reaction from wind and light changes. Thus, it will be helpful to reduce the error if we recognize the characteristics of the surrounding areas around observation stations.

Spring phenological events in South Korea have been advanced about three to 19 days from 1973 to 2008. In the same period, the spring temperature has increased about 1.6 °C. Apricot particularly suffers significant impacts due to the remarkable ratio increase of the minimum temperature in January and the maximum temperature in February. The change ratio of Yoshino cherry is higher than two shrubs, forsythia and azalea. The results are different from Menzel's [38] study that shrubs seem to be more responsive to changes in temperature than are trees. Apricot and Yoshino cherry trees are feasible species that are greatly influenced by climate factors and environmental conditions. Especially, Yoshino cherry is so sensitive to temperature changes that many studies have been performed because the species plays an indicator role (Ho et al., 2006; [35]. Yoshino cherry has been grown as an early-blooming tree, typically in late January or February. This shows the large influences by late winter of the remarkable impact of global warming and, thus, the significant urbanization effect. As a result, the urbanization effect is largely influencing South Korea, as opposed to global warming. The phenological event change ratio in Clusters 2 and 3 of Type II is evidence of this. This region is the same as Cluster 2 of Type I; however, the change ratio in Cluster 3 of Type II is very large, so it leads the overall changes in Clusters 2 and 3 of Type II [34]. Additionally, over 30% of this region is urban, so this helps prove the results. It is difficult to measure the correct gap of the increasing temperature by global warming because there must be an increasing temperature due to urbanization. After 1980, because urbanization effects vividly existed with respect to the average temperature range in South Korea, the country saw an increase in the temperature of approximately 1.17 °C in the past three decades and an increase in temperature of about 0.76 °C with the deletion of urbanization effects. Nominated cities are metropolitan areas and cities with populations over 1,000,000. This is why the large gap between cities and rural areas were measured and it might also be worth comparing between medium-sized or small-sized cities and rural areas. Additionally, it will be meaningful to think about the phenological event changes by carbon occurrences from industrial cities. There are carbon cycle studies [39] and if the climate sensitive plants are added in they would, again, have a significant contribution to phenological studies. There were some cases that shrubs showed positive correlations in urban areas. These phenomena are the evidence that explain the increase of temperature and changes of surrounding factors due to urbanization [40]. The quality of the air and the decreasing amount of light from buildings were the factors for impacting shrubs.

6. Conclusions

Climatic factors are affected by temperature, wind, rain and drought in the area and they influence the behavior of humans. Some studies show that there is a range in the bioclimatic comfort zone in which people feel comfortable. People believed the phonological events of plants can determine their time of spring so that natural changes should influence an active scenario in the city to protect from damaging socioeconomic and politic problems.

In this study, changing trends, like the budding and flowering dates of spring plants, due to climate factors occurred in the process of urbanization. Four common species, such as *Forsythia koreana* (forsythia), *Rhododendron mucronulatum* (azalea), *Prunus yedoensis* (Yoshino cherry) and *Prunus mume* (Japanese apricot) are examined. The inland phonological response in relatively cold and dry areas are affected by Siberian high atmospheric pressure. On the other hand, the south and east coastlines are humid and warm areas even in the winter season due to the southeastern wind.

There were advancements for 3.1 days of forsythia, 5.5 days of azalea, 6.5 days of Yoshino cherry and 18.6 days of Japanese apricot during the research period. The greatest changes occurred in January (minimum temperature) and February (maximum temperature) and the precipitation change was not so influential.

South Korea is characterized with a small amount of land and high population densities in cities, thus it is strong influenced by global warming, as well as urbanization. Seven metropolitan cities and Suwon have populations over 1 million, showing more remarkable phenological events and changes of climate factors than the other regions. Especially in the case of shrubs, the phenological events were delayed in urban areas during this research. In conclusion, climate change, as well as urbanization, serves as strong factors leading to phonological and regional events of the ecosystem.

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