Journal of Plant Biology, March 2000, 43(1) : 10-17

Comparison of Phenological Characteristics for Several Woody Plants in Urban Climates

Byeong Mee Min*
Department of Science Education, College of Education, Dankook University, Seoul 140-714, Korea

Phenological properties of woody species were compared between two urban climates during 1997 and 1998. The study areas were Chungdam Park, Chungdam-dong, Kangnam-gu, Seoul (the urban center, 43 species) and Namhansansung Area, Sansung-ri, Joongbu-myon, Kwangju Gun, Kyonggi Province (the urban periphery, 16 species). Distance between these sites was 13.5 km. The differences of budding, foliation, and flowering times (1997 versus 1998) were 10.9, 3.2, and 7.4 days, respectively. Species that budded and flowered earlier were strongly influenced by Nuttonson's Index (Tn) of February and March, but those with later dates were only weakly influenced. Unlike for budding and flowering times, foliation time was determined by air temperature or other factors in the leaf-growing season rather than by Tn. The Tn influence over phenology was stronger in shrubs and lianas than in trees. Phenophases in Chungdam Park appeared earlier than those in the Namhansansung area. The phenological differences between the two areas were 7.3 days in budding time, 8.3 days in foliation time, and 10.2 days in flowering time in mean values, with variations among species. Based on flowering-time data, the phenological variation between the two areas was equivalent to a 2.5° latitude difference. Budding time varied the most (20 days) in *Zelkova serrata*, compared with only 3 days for *Prunus padus*. Differences in foliation time ranged from 15 days (in *Alnus hirsuta* and *Styrax obassia*) to 0 days (*P. padus*). Flowering time differences were largest (24 days) in *Rhododendron mucronulatum* and smallest (2 days) in *P. padus*. One can conclude that heat pollution in the urban center in Seoul severely changed phenology, and that sensitivity to that pollution differed among plant species.

Keywords: Air temperature, Budding time, Flowering time, Nuttonson's Index, Phenology, Urban climate

Several factors affect woody plant phenology, including air temperature, soil moisture (Flint, 1974; Lucier and Hinckley, 1982; Jackson and Bliss, 1984), daytime length (Garner and Allard, 1920), and plant water potential (Baker et al., 1982). Of these, air temperature is the most critical factor during the early stages of the growing season in temperate deciduous forests (Brown, 1953). Activity time of an organism can be delayed about 4 days with each 1° increase in latitude (Hopkins, 1920). In 1940 the cumulative air temperature-time concept was introduced. Since then, macroclimate calculations of daily cumulative temperature (Nuttonson's Index, Tn; Lindsey and Newman, 1953), warmth index (Kira, 1945) and year day index (Yim et al., 1983; Yim, 1986) have also been suggested. However, microclimate also greatly affects foliation and flowering. for example, phenological properties may change with geographical condition, topography, altitude, or the slope and location of a twig, even though latitude and species are the same (Moony and Billings, 1961).

*Corresponding author; fax +82-2-796-2857
e-mail bmeemin@hanmail.net

Because of structural heating systems and automobile waste heat, the wintertime air temperature in an urban center can be higher than in the urban periphery, even though the macroclimate is the same. Climatic changes in urban areas have been studied extensively (Landsberg, 1957; Chandler, 1976; Oke, 1979; Cho et al., 1988; Lee, 1997). This heat-island phenomenon of urban centers frequently arises in congested areas, where an increase in air temperature is more conspicuous at night than in the daytime (Chandler, 1965; Bernstein, 1968; Peterson, 1969; Oke and East, 1971). Because of the heat-island phenomenon during the winter, the phenophase times in the early growing season vary for plants growing in urban areas versus those in the urban periphery.

Plant phenology is interrelated with the activities of herbivores or pollinators, so changes in phenology may reflect the imbalance of the ecosystem, and possible destruction of that ecosystem, in extreme cases. Flowering time, especially, which must coincide with the action of pollinators, affects seed productivity. These changes are meaningful in ecological studies (Schemske, 1977; Augspurger, 1981; Gross and

Werner, 1983; English-Loeb and Karban, 1992; John and Schemske, 1998).

Heat pollution in these urban areas modifies the ecosystem, making it an important topic in numerous phenological studies at sites throughout the world (Taylor, 1972; Heideman, 1989; Milton, 1991; Wright, 1991). However, although much phenological data have been accumulated in Korea (Yim and Cho, 1977; Yim, 1979; Yim, 1983; Yim et al., 1983; Kim and Ryu, 1985; Yim, 1987; Min and Choi, 1993), few studies have monitored those changes in woody plants due to heat pollution there.

In this paper, properties of change caused by heat pollution in urban centers were clarified. Specifically, the phenology of several woody plants were compared among two areas in which macroclimate was similar but microclimate was not.

STUDY AREAS AND METHODS

The two study areas are shown in Figure 1. Chungdam Park, an urban center, is located in Chungdam-dong, Kangnam-gu, Seoul (37° 31′ N, 127° 03′ E). Namhansansung area, outside the urban area, is 13.5 km to the east, in Sansung-ri, Joongbu-myon, Kwangju-gun, Kyonggi Province (37° 28′ N, 127° 12′ E). The altitudes of the two sites are 50 m and 320 m, respectively. Between the two is a mountain, with an elevation of 450 m.

Chungdam Park comprises 57,854 m^2, and is surrounded by residential areas and paved roads. Sixty percent of its total area is planted with *Populus tomentiglandulosa* and *Robinia pseudoacacia*; the remainder is a semi-natural forest composed of *Quercus* species. Because the forest had been managed

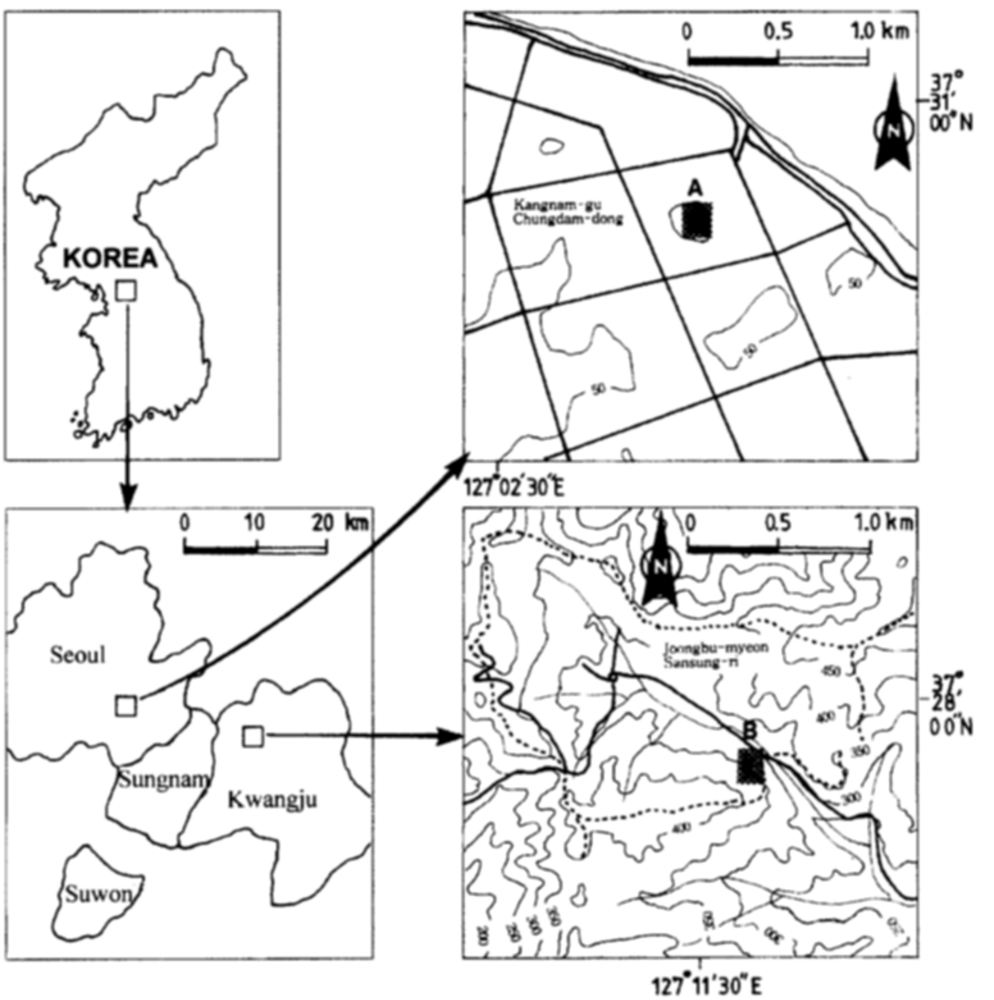

Figure 1. A map of the study areas.

under a city plan, vegetation was poorly stratified. Trails are found throughout the forest and up to the peak, which results in strong human impact. The population of vascular plants consists of 248 species, in 79 families, with foreign species comprising 19% of the total.

The vegetation and environment in the Namhansansung area was described by Min and Choi (1993). This second study area is a natural forest composed of *Quercus mongolica, Quercus serrata, Carpinus tschonoskii, Betula davurica, Maackia amurensis,* and *Prunus sargentii*. Vegetation is stratified into four distinct layers. Except for one main trail, there is little human impact. This region has a 5% east slope.

Based on average plant size and geographical conditions, 3 to 6 standard plants per species were chosen at each study area. A total of 43 species was collected on Mar. 10, 1997, in Chungdam Park. In addition, 16 species were sampled on Mar. 13, 1998 in the Namhansansung area. These 16 species were also found growing in Chungdam Park. Scientific names of tree species were assigned according to Lee (1979).

At each site, a field survey was carried out twice a week from March to April, then once a week from May to June, for Chungdam Park (in both 1997 and 1998) and for Namhansansung (1998 only). The phenophase survey followed the method of Min and Choi (1993). That is, budding, onset and completion of foliation, flower budding, flowering, flower falling, and fruiting times were recorded.

Weather statistics were based on data from Seoul Station (37° 34′ N, 126° 58′ E), as provided by the Korea Meteorological Administration (1997~1998). Nuttonson's Index, Tn, was determined as follows, according to Yim (1987) but with one modification (i.e., minus 5°C, rather than 43° F, was used in this study):

Tn = Σ(mean daily air temperature-5), in day of 5°C ≤

RESULTS AND DISCUSSIONS

Climate

The Tn from February to June, in both years, is shown in Figure 2. Because the values for February and March most strongly influence budding time, the Tn curves for this period are magnified (Fig. 2B). Values determined in 1998 were consistently higher than those of 1997.

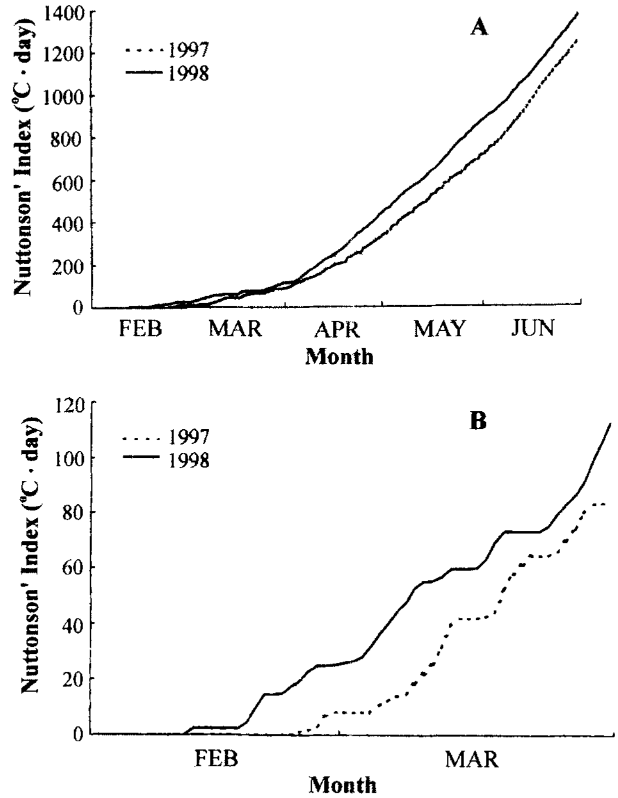

Figure 2. Nuttonson's Index (Tn) of the study area from February to June. Data were from the Monthly Weather Report of the Korea Meteorological Administration (Seoul Station). A; from February to June, B; from February to March.

For Chungdam Park, Tn values reached 50°C·day on Mar. 19, 1997, and Mar. 9, 1998; values of 100°C·day were calculated on Apr. 3, 1997, and Mar. 30, 1998. Therefore, the difference in budding time between the two years was 10 days in 50°C·day and 4 days in 100°C·day. Thereafter, differences increased to 10 days again, when the values reached 550°C·day. Accordingly, the air temperature also was higher in 1998 than in 1997, throughout the first half of March, but this trend was reversed in the second half of that month. From the first half of April, the air temperature, again, was higher in 1998 than in 1997. Beginning in early May, these differences remained constant to the end of June.

Phenology

The phenological properties of the woody plant species were studied at Chungdam Park (both 1997 and 1998) and in the Namhansansung area (1998 only). In 1997, budding at Chungdam Park occurred as early as the beginning of March for *Ribes fasciculatum* var. *chinense* and *Eleagnus umbellata*, and as late as April 20 for *Albizzia julibrissin* and *Lespedeza cyrtobotrya*. The next species to bud were *Alnus hirsuta, Rosa multiflora, Prunus armeniaca* var. *ansu, Prunus padus,* and *Syringa dilata*, which flushed in mid-March.

The earliest species to complete foliation (in late March) were *R. fasciculatum* var. *chinensis, R. multiflora, Spiraea prunifolia* for. *simpliciflora, P. armeniaca* var. *ansu, P. padus, E. umbellata,* and *Viburnum sargentii* for. *sterile*. Species such as *Salix koreensis, Quercus acutissima, Quercus variabilis, A. julibrissin, L. cyrtobotrya, M. amurensis, Hibiscus syriacus, Diospyros kaki,* and *Paulownia coreana* completed their foliation in late April. In general, the relative foliation time of a species largely corresponded to its relative budding time. However, even though *S. koreensis, Quercus dentata, M. amurensis,* and *H. syriacus* budded late, they foliated early, so that the leaves of these species grew rapidly.

Woody plants of *Larix leptolepis, Populus tomentiglandulosa, S. koreensis, Corylus heterophylla* var. *thunbergii, Lindera obtusiloba, Rhododendron mucronulatum,* and *A. hirsuta* were the first to flower, in mid- or late March. In contrast, *Castanea crenata, A. julibrissin, L. cyrtobotrya, D. kaki, Styrax japonica,* and *Ligustrum obtusifolium* flowered last, in early June.

The properties monitored for phenophase appeared earlier in 1998 than in 1997, at rates of 10.9, 3.2, and 7.4 days for budding, foliation, and flowering times, respectively. The overall differences between the two years ranged from 26 days (*Magnolia kobus*) down to >10 days in 26 species (including *Larix leptolepis*). The rest of the species showed differences of only 1~9 days. Budding times of *Q. variabilis, C. crenata,* and *D. kaki* were 1~3 days earlier in 1997.

Because the budding for all species occurred from early March to mid-April, this property was probably affected by the Tn value of February and March. For example, when the mid-March Tn value of 50°C·day differed between the two years by 10 days, the difference in budding date was >10 days for species flushing at that time. However, this Tn value influence on budding varied among species. In fact, the relationship between Tn values and budding times for *Q. variabilis, C. crenata,* and *D. kaki* were the reverse. These species budded in April and air temperature during this period in 1997 was higher than in 1998.

Foliation times in 1997 and 1998 differed by 18 days for *R. multiflora*, by over 10 days for both *R. fasciculatum* var. *chinense* and *Malus baccata* for. *minor*, and by −5~7 days for the others. The foliation time for six species, including *R. pseudoacacia*, was earlier in 1997 than in 1998. In general, the differences in foliation time compared with budding time were small. Therefore, budding and foliation times were affected by Tn and the air temperature of that time, respectively.

The differences in flowering time between the two years were 18 days in *E. umbellata* and *Forsythia koreana*; >10 days for 10 other species, including *C. heterophylla* var. *thunbergii*; and <9 days for the remainder. *R. multiflora* and *Prunus serrulata* var. *spontanea* flowered earlier in 1997 than in 1998. Unlike with budding, the time difference between 1997 and 1998 was not always large in the species that flowered early in the season, but was probably an intrinsic property of the particular species. Those species at Chungdam Park whose phenological prop-

Table 1. Phenological differences between 1997 and 1998 for species found in Chungdam Park.

Species	Budding time	Foliation time	Flowering time
Magnolia kobus	III		
Ribes fasciculatum var. *chinense*	II	II	I
Rosa multiflora	II	II	
Eleagnus umbellata	II		II
Forsythia koreana	II		II
Malus baccata for. *minor*	II	I	I
Lindera obtusiloba	II		I
Rhododendron mucronulatum	II		I
Ligustrum obtusifolium	II		I
Viburnum sargentii for. *sterile*	II		I
Sorbus alnifolia	II		
Acer palmatum	II		
Larix leptolepis	II		
Salix koreensis	II		
Betula platyphylla var. *japonica*	II		
Styrax obassia	II		
Diospyros kaki			II
Styrax japonica	I		I
Corylus heterophylla var. *thunbergii*	I		I
Alnus hirsuta	I		I
Symplocos chinensis for. *pilosa*	I		I
Zelkova serrata	I		
Spiraea prunifolia for. *simpliciflora*	I		
Prunus sargentii	I		
Prunus serrulata var. *spontanea*	I		
Euonymus alatus var. *ciliatodentatus*	I		
Acer burgerianum	I		
Hibiscus syriacus	I		
Syringa dilatata	I		
Quercus acutissima			I
Prunus padus			I
Albizzia julibrissin			I
Robinia pseudoacacia			I

I, 8~14 days; II, 15~21 days; III, 22~28 days.

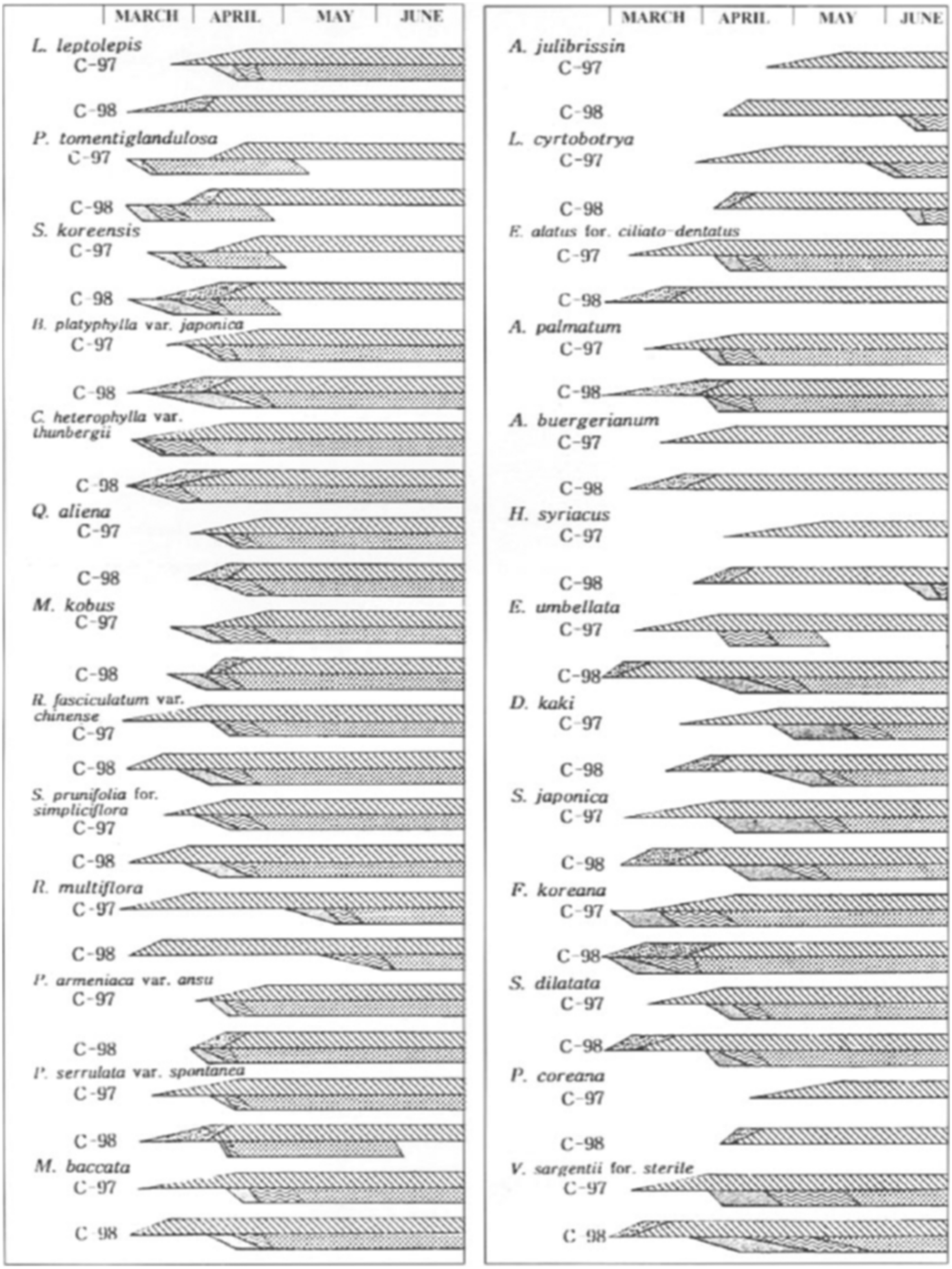

Figure 3. Phenophases of woody plants early in the growing season at Chungdam Park (C) and Namhansansung area (N).

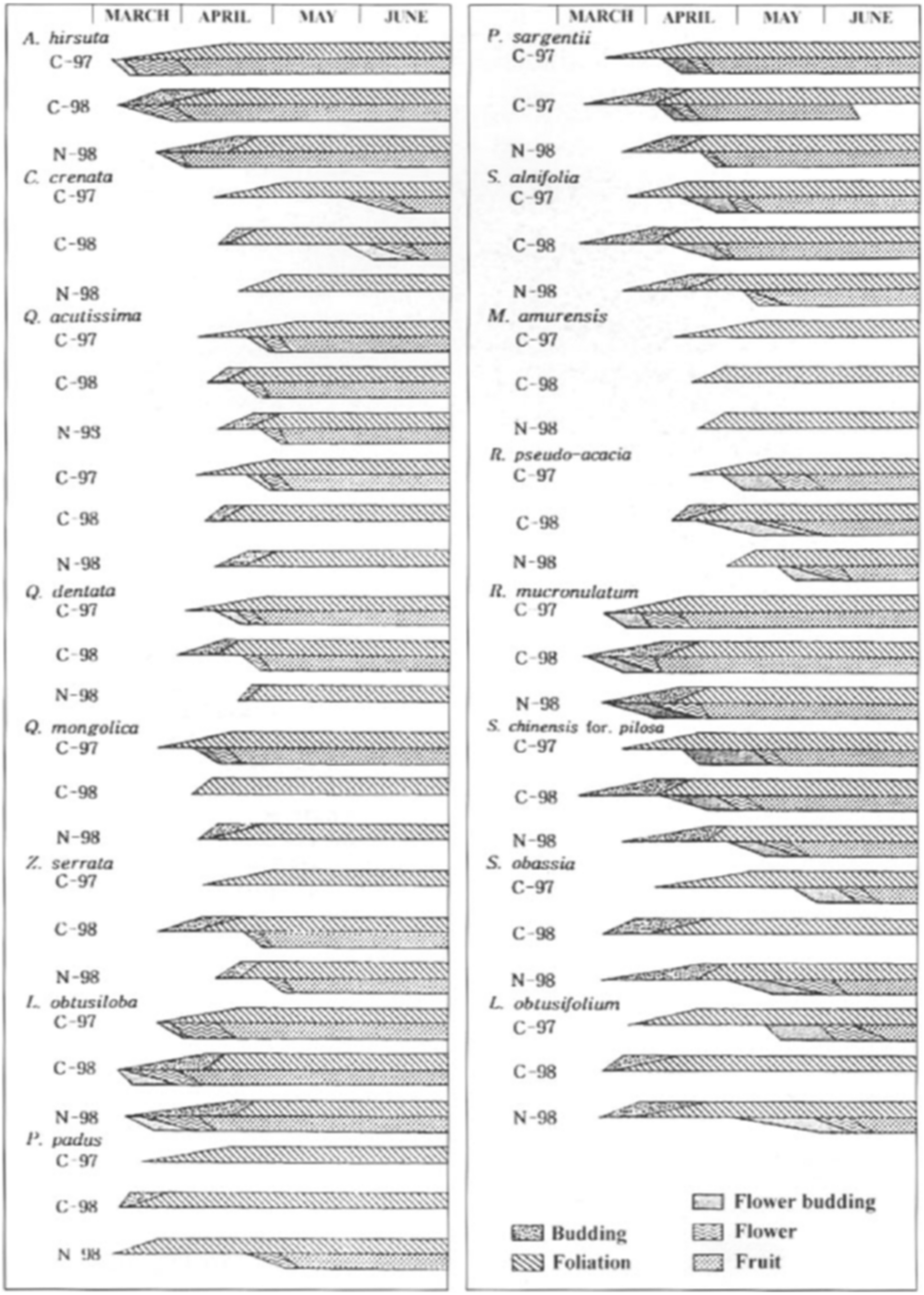

Figure 3. Continued

erties differed by more than one week between 1997 and 1998 are shown in Table 1.

The phenophases of the 16 species studied in the Namhansansung area appeared later (Fig. 3, Table 2). The mean differences for budding, foliation, and flowering times were 7.3, 8.3, and 10.2 days, respectively. Of these three phenological properties, the dates for flowering time differed the most between the two study areas.

At Namhansansung, budding occurred later than at Chungdam Park, by 20 days in *Zelkova serrata*; 13 days in *A. hirsuta, P. sargentii, Sorbus alnifolia,* and *Symplocos chinensis* for. *pilosa*; and less than 9 days for the other species (Table 2). Budding time of *P. padus*, however, was 3 days earlier in the Namhansansung area.

When dates for foliation were checked, differences between the two areas were 15 days in *A. hirsuta* and *Styrax obassia*; 0 days in *P. padus*; and 2~14 days for the other species. For occurrence of flowering, the differences between the two areas were 24 days in *R. mucronulatum*, 21 days in *A. hirsuta*, 2 days in *P. padus*, and 3~14 days for the rest. When the timing of shrubs and trees was checked for consistency between plant type, *R. mucronulatum,* a shrub, flowered early in the growing season, but two of the tree species, *A. hirsuta* and *P. padus,* did not flower at the same time as each other. Species which had phenological differences of more than one week, between Chungdam Park and the Namhansansung area, are shown in Table 2.

In summary, the species in which phenophases appeared earliest were more responsive to climatic change than those which developed later. In addition, budding, foliation, and flowering times were determined by the Tn value in February and March, air temperature during the leaf-growth period, and the value of Tn value up to flowering time, respectively.

Table 2. The phenological differences between plant species found in Chungdam Park and in the Namhansansung area.

Species	Phenophase		
	Budding time	Foliation time	Flowering time
Rhododendron mucronulatum	–	–	III
Alnus hirsuta	II	II	II
Zelkova serrata	II	I	–
Styrax obassia	–	II	–
Prunus sargentii	I	I	I
Sorbus alnifolia	I	I	I
Symplocos chinensis for. *Pilosa*	I	I	I
Castanea crenata	I	I	–

I, 7~14 days; ,II 15~21days; III, 22~28 days.

Although flowering time was sensitive to the microclimate, foliation time was only weakly affected. Therefore, the flowering time was probably determined by air temperature. However, this phenomenon could also be explained by the fact that, regardless of species, the sampled plants all had similar mechanisms for responding to environmental changes. In contrast, foliation time for a particular species could be decided not only by air temperature but also by such factors as water (Mooney and Billings, 1961; Min and Choi, 1993).

Finally, the plants that showed phenological responses to environmental changes included some tree species, but most were shrubs or lianas. These sensitive species were *R. fasciculatum* var. *chinense, R. multiflora, E. umbellata, R. mucronulatum, F. koreana, S. obassia, V. sargentii* for. *sterile, S. chinensis* for. *pilosa, M. baccata* for. *minor, S. alnifolia,* and *P. sargentii.* Those species, all trees, that were insensitive to environmental changes included *Q. aliena, Q. variabilis, P. coreana, P. padus, M. amurensis,* and *C. crenata*.

Flowering time was earlier in Chungdam Park, by 10.2 days, because of an apparent gap in the microclimate (air temperature mainly) between the two study areas. This corresponds to a difference of 2.5° latitude. As an example of this microclimatic gap, from January to March of 1987 the mean daily air temperature (MDAT) of Mapo (Seoul), in the urban center, was 1.2°C higher than at Bogjung-dong (Sungnam), which is located outside the city (Cho et al., 1988). In the springtime, the maximum MDAT for Mapo was 4°C higher than that for Bogjung-dong. The MDAT at Chungdam Park was equal to or higher than that at Mapo. Therefore, the difference in MDAT between the two study areas was estimated at >3°C in the springtime. Because of this heat-island phenomenon in the urban area, phenology probably was severely changed in Seoul city's forest compared with that of the outside area.

In the future, not only will the general air temperature increase in Seoul city (Cho et al., 1988; Lee, 1997) but waste heat also will seriously affect phenological properties. This will have an impact first on herbivores and pollinators, then on the ecosystem.

Received September 29, 1999; accepted February 14, 2000.

LITERATURE CITED

Augspurger CK (1981) Reproductive synchrony of a tropical shrub: Experimental studies on effects of pollinators and seed predators on *Hybanthus prunifolius* (Violaceae). Ecology 62: 775-778

Baker GA, Rundel PW, Parson DJ (1982) Comparative phenology and growth in three chaparral shrubs. Bot Gaz 143: 94-100

Bernstein RD (1968) Observation of the urban heat-island effect in New York City. J App Meteor 7: 575-582

Brown DS (1953) Climate in relation to deciduous fruit production in California. VI. The apparent efficiencies of different temperatures for the development of apricot fruit. Proc Amer Soc Hort Sci 62: 173-183

Chandler TJ (1965) The climate of London. Hutchinson, London

Chandler TJ (1976) Urban climatology and its relevance to urban design. WMO No. 483

Cho H-M, Cho C-H, Chung K-W (1988) Air temperature changes due to urbanization in Seoul area. J Kor Met Soc 24: 27-37

English-Loeb GM, Karban R (1992) Consequences of variation in flowering phenology for seed head herbivory and reproductive success in *Erigeron glaucus* (Compositae). Oecologia 89: 588-595

Flint HL (1974) Phenology and genecology of woody plants, *In* H Lieth, ed, Phenology and Seasonality Modeling, Springer-Verlag, New York, pp 83-97

Garner WW, Allard HA (1920) Effect of the relative length of the day and night and other factors of the environment on growth and reproduction in plant. J Agric Res 18: 553-606

Gross RS, Werner PA (1983) Relationships among flowering phenology, insect visitors, and seed-set of individuals: Experimental studies on four co-occurring species of goldenrod (*Solidago*: Compositae). Ecol Monogr 53: 95-117

Heideman PD (1989) Temporal and spatial variation in the phenology of flowering in a tropical rainforest. J Ecol 77: 1059-1079

Hopkins AD (1920) The bioclimatic law. J Wash Acad Sci 10: 34-40

Jackson LE, Bliss LC (1984) Phenology and water relations of three plant forms in a dry tree-lined meadow. Ecology 65: 1302-1314

John GB, Schemske DW (1998) Variation in flowering phenology and its consequences for lupines colonizing Mount St. Helens. Ecology 79: 534-546

Kim J-H, Ryu BT (1985) On the flowering and leafing time of *Rhododendron mucronulatum* and *R. schlippenbachii* along elevation at Mt. Kwanak. Kor J Ecol 8: 53-59

Kira T (1945) A New classification of climate in eastern Asia as the basis for agricultural geography. Hort Inst, Kyoto Univ, Kyoto

Korea Meteorological Administration (1997-1998) Monthly weather report (from Feb. to June). p 49

Landsberg HE (1957) Review of climatology, 1951-1855. Meteor Monogr 3: 110-130

Lee H-Y (1997) Urban climate and urban ecology. Kor J Env Ecol 11: 224-229

Lee TB (1979) Illustrated Flora of Korea. Hyangmumsa, Seoul

Lindsey AA, Newman JE (1953) Use of official weather data in springtime temperature analysis of an Indiana phenological record. Ecology 37: 812-823

Lucier AA, Hinckley TM (1982) Phenology growth and water relations of irrigated and non-irrigated black walnut. Forest Ecol Manage 4: 127-142

Milton K (1991) Leaf change and fruit production in six neotropical Moraceae species. J Ecol 79: 1-26

Min BM, Choi JK (1993) A phenological study of several woody plants. Kor J Ecol 16: 477-483

Mooney HA, Billings WS (1961) Comparative physiological ecology of arctic and alpine population of *Oxyria digyna*. Ecol Monogr 31: 1-29

Oke TR (1979) Review of urban climatology 1973-1976. WMO No. 539, p 100

Oke TR, East C (1971) The urban boundary layer in Montreal. Boundary Layer Meteor 1: 411-437

Peterson JT (1969) The climate of cities: A survey of recent literature. US Dept Health, Education and Welfare, National Air Pollution Control Admin. Raleigh, N.C. p 48

Schemske DW (1977) Flowering phenology and seed set in *Claytonia virginica* (Portulacaceae). Bull Torrey Bot Club 104: 254-263

Taylor FG Jr (1972) Phenodynamics of production in mesic deciduous forest, *In*, H Lieth, ed, Phenology and Seasonality Modeling, Springer-Verlag, New York, pp 237-254

Wreight SJ (1991) Seasonal drought and the phenology of understory shrubs in a tropical moist forest. Ecology 72: 1643-1657

Yim Y-J (1979) Phenological study on the leafing of woody plant species with the thermal conditions in Korea. J National Sciences, Republic of Korea (Natural Science) 18: 103-122

Yim Y-J (1983) The thermal climate and phenology in Korea. J Plant Biol (Kor J Bot) 26: 101-107

Yim Y-J (1986) The effects of thermal climate on the flowering dates of plants in South Korea. Kor J Apicult 1: 67-84

Yim Y-J (1987) The effects of thermal climate on the flowering dates of plants in South Korea. For the exploitation of honey and pollen resources plants. Kor J Apicult 2: 9-28

Yim Y-J, Cho M (1977) On the flowering dates of the woody plant species in Hongneung Arboretum, Seoul. Kor J Ecol 1: 17-34

Yim Y-J, Rim M-K, Shim J-K (1983) The thermal climate and phenology in Korea. J Plant Biol (Kor J Bot) 26: 101-117