Holocene Vegetation Responses to East Asian Monsoonal Changes in South Korea

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1. Introduction

The Korean Peninsula, surrounded by the sea on three sides (east, west, and south), is located on the eastern end of the Asian continent adjacent to the West Pacific and belongs to the temperate zone with four distinct seasons, which are largely controlled by the East Asian monsoon. During the winter, from December to February, it is cold and dry due to the establishment of the strong Siberian anticyclone on the Tibetan Plateau. Meanwhile, the summer, from June to August, is hot and wet, with frequent heavy rains (An, 2000; Nakagawa et al., 2006; Yancheva et al., 2007). The modern climate of Korea is characterized by a mean annual temperature of 12.2℃, ranging from 5.1℃ to 13.6℃, with a monthly mean daily maximum temperature of up to 19.4℃ and a monthly mean daily minimum temperature of 0℃ over the past 30 years (1971–2000). Precipitation is relatively high (mean, 1299 mm), and about 70% of the annual precipitation falls in summer, especially from June to August (Korean Meteorological Administration, http://kma.go.kr).

Pollen studies are well suited to examining the impact of rapid climate change on terrestrial ecosystems because the reponse of vegetation to climate fluctuation is pronounced and can occur on decadal time scales (Tinner & Lotter, 2001). Pollen analysis provides information that is unavailable from other sources and offers a unique and invaluable perspective on natural, climate-induced vegetation changes and environmental reconstruction (Birks & Birks, 1980; Davis, 1994) despite its limitations compared with marcropaleontology. Therefore, among the various terrestrial paleoclimate proxies, pollen has proven to be a most useful tool.

Pollen studies were carried out in South Korea with a focus mainly on reconstructing vegetation and climate from the Quaternary sediments of wetlands (e.g., Chang et al., 1987; Choi et al., 2005; Jang et al., 2006; Jun et al., 2010; Park & Yi, 2008; Yi et al., 2004, 2005, 2008a, 2008b; Yoon, 1997), lakes (e.g., Chang & Kim, 1982; Fujiki & Yasuda, 2004; Yasuda et al., 1980), and archaeological sites (e.g., Chung et al., 2006, 2010; Yi, 2011; Yi & Kang, 2009; Yi & Kim, 2009; Yi et al., 2011; Yoon et al., 2005). Early, non-dated pollen studies were conducted to interpret local vegetation history. Recently, pollen investigations have reconstructed vegetation and climate changes with geologic ages using radiocarbon dates.

The age-controlled pollen data are used herein. The response of vegetation in South Korea to East Asian monsoon climate change is discussed based on the pollen datasets.

2. East Asian monsoon

The East Asian monsoon is an integral part of the global climatic system. Monsoon climates, especially monsoon-derived precipitation, are important to the maintenance of the environments of East Asia. This monsoon regime is a sub-system of the Asian monsoon circulation (An, 2000). The East Asian monsoon is formed by thermal differences between the Asian landmass and the Pacific Ocean; the area to the northwest of the front is under the strong influence of the continental Siberian air mass, which is dry and has large seasonal temperature variations, whereas the area to the southeast of the front is controlled by the oceanic Pacific air mass, which is high in moisture and has small seasonal temperature variations (Yancheva et al., 2007). The coastal East Asian regions are characterized by prominent seasonality due to the seasonal migration of the monsoon front across these regions (Nakagawa et al., 2006). As the seasonal temperature variability on the continent is greater than that in the ocean, the temperature gradient between the two air masses creates a surface-air pressure gradient that seasonally changes its direction, forcing NW and SE surface winds in winter and summer, respectively (Fig. 1).

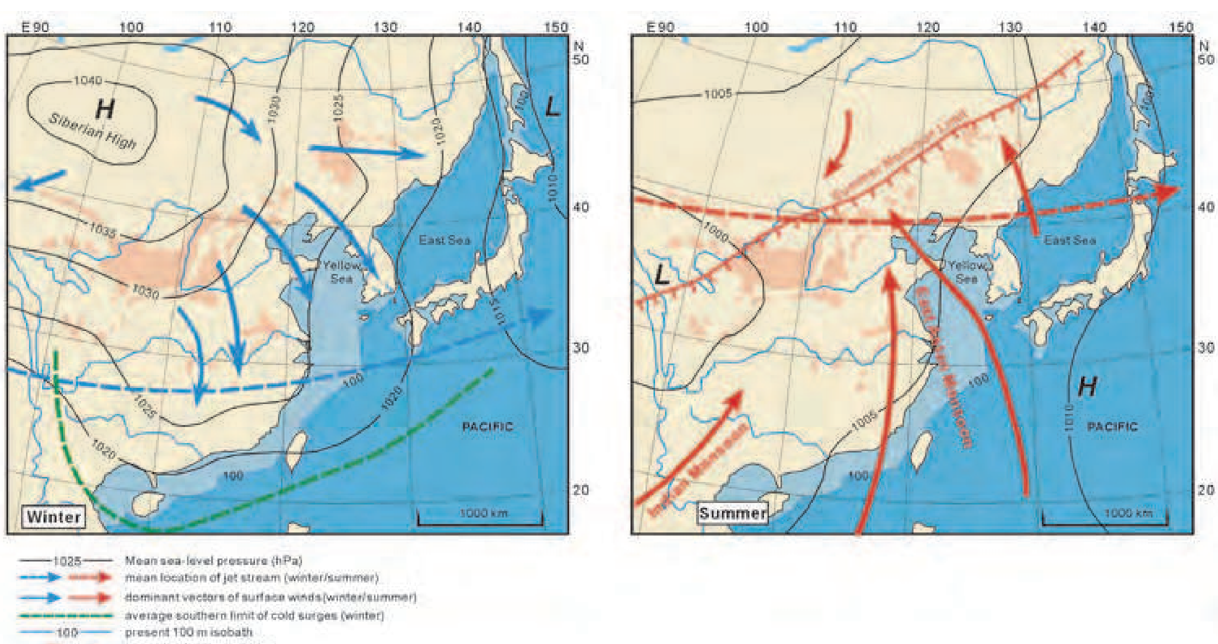

Fig. 1. Seasonal changes in the wind system of the East Asian monsoon area (modified from Yancheva et al., 2007).

2.1 Evolution of the East Asian monsoon

The evolution of the East Asian monsoon is a principal factor controlling paleoenvironmental changes in the East Asian region (An, 2000). Cenozoic uplift of the Himalayan–Tibetan Plateau is thought to contribute to the Asian Monsoons, including the East Asian and Indian monsoons, and the Northern Hemispheric ice ages (Qiang et al., 2001). Qiang et al.'s (2001) study of the magnetostratigraphy of the Jiaxian red clay section of the Chinese Loess Plateau documented that the onset of the East Asian monsoon occurred in the Late Miocene (8.35 Ma). Moreover they recognized long-term changes in the East Asian monsoon since the Late Miocene based on accumulation rate and grain size analysis of the eolian dust deposited in the central Chinese Loess Plateau. For example, the strengthening of the East Asian winter monsoon occurred between 3.5 Ma and 3.1 Ma and intensified further after 2.6 Ma. However, Sun and Wang (2005), based on compilation of paleobotanical and lithological data from China, suggested that an initiation of monsoon climate system in East Asia was further back to the latest Oligocene. Subsequently, paleomonsoonal studies have used multi-proxies of loess–paleosols (e.g., An, 2000; An et al., 1990), caves (e.g., Dykoski et al., 2005; Wang et al., 2001), lake sediments (e.g., Nakagawa et al., 2006; Wu et al., 2006; Wűnnemann et al., 2006; Yamada, 2004), ice cores (e.g., Yao et al., 2001), and pollen (e.g., Feng et al., 2006; Makohonienko et al., 2008; Yi et al., 2003a, 2003b).

2.2 Modern climate of Korea

South Korea is in the temperate zone controlled by the East Asian monsoon, which is characterized by distinct seasonal changes, with a warm, wet summer and a cool, dry winter. However, the present climate conditions are trending toward increases in extreme precipitation and drought.

Baek and Kwon (2005) showed a decreasing trend in April precipitation and an increasing trend in August precipitation for 1954–2002. Chang and Kown (2007) investigated the spatial patterns of trends in summer precipitation for 1973–2005 and pointed out a significant increase in June precipitation for the northern and central-western part of Korea. Bae et al. (2008) reported that the long-term trends in annual precipitation and runoff were increasing in the northern part of Korea and decreasing in the southwestern part of Korea. Furthermore, a recent study on climate trends in Korea reported annual precipitation increases and increases in the number of severe precipitation events (Jun et al., 2010). It showed that the increase in annual precipitation is mainly associated with increases in the frequency and intensity of heavy precipitation during the summer season (June–September), whereas precipitation during the spring and winter seasons showed a decreasing trend. This variation in precipitation is likely to increase flood and drought risk.

3. Vegetation of Korea

The first studies of Korean plants were made by Japanese researchers (e.g., Nakai, 1952; Uyeki, 1911, 1933), followed by Korean botanists (e.g., Chung & Lee, 1965; Kong, 2007; Lee, 1985; Lee & Yim, 2002; Yim, 1977; Yim & Kira, 1975). Yim and Kira (1975) first established a vegetation map of the Korean Peninsula, which consists of conifer forest (subalpine zone), deciduous broadleaved forest (temperate zone), and evergreen forest (subtropical zone). The deciduous broadleaved forest is further divided into three zones at different latitudes: the northwest temperate zone, the central temperate zone, and the southern temperate zone. Moreover, the vertical vegetation zone is divided on the basis of the elevation of mountain ranges. Local vegetation is primarily controlled by climate, soil, geomorphology, and artificial factors. In all, the distribution of Korean forests is band-shaped and changes with variations in temperature depending on latitude and elevation (Fig. 2).

Temperature is an important factor in the growth and distribution of plants. The mean annual temperature in Korea is 2.5–10.0°C in the northern region (39°N–43°N), 10.0–12.5°C in

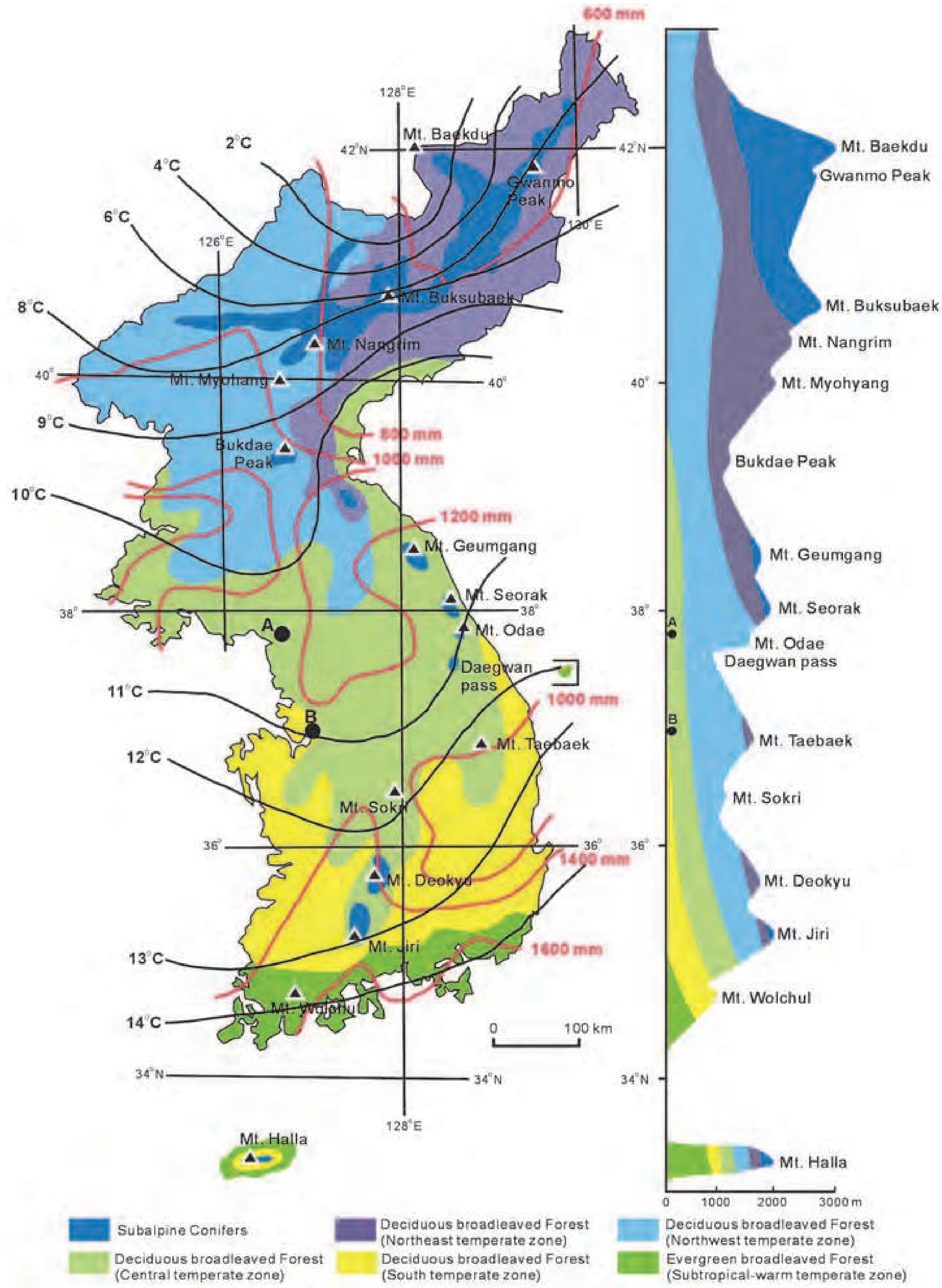

Fig. 2. Vertical and latitudinal modern vegetation map with an isothermal and an isobaric line (modified from Yim & Kira, 1975). N–S cross-section showing the forests distributed across the peninsula with elevation. Pollen records discussed in the text are from the Paju-Unjeong site (A) and Pyeongtaek site (B).

the central region (37°N–39°N), and 12.5–15.0℃ in the southern region (33°N–37°N). The mean monthly daily maximum temperature is 32.5–35℃ in the northern region and 37.5–40.0℃ in the southern region; the mean daily minimum temperature ranges from -5℃ to -15℃ in the subtropical region, -15℃ to -20℃ in the warm-temperate south central region, -20℃ to -25℃ in the warm-temperate central region, -25℃ to -30℃ in the warm-temperate north central region, and -35℃ to -45℃ in the subalpine northern region (Kong, 2007). Subalpine conifer forest is mainly distributed in North Korea and consists of evergreen conifers, such as a fir (*Abies holophylla, A. koreana, A. nephrolepsis*), spruce (*Picea jezoenisis*), pine (*Pinus koraiensis, P. pumila*), and yew (*Taxus cuspidate*), and deciduous broadleaved trees, such as birch (*Betula costata*, and *B. platyphylla* var. *japonica*). These hardwood trees grow under subalpine climate conditions, with a mean annual temperature of 5℃ (Fig. 3a, 3b).

Mixed conifer and deciduous broadleaved forests are dominated by pines (*Pinus desiflora*) and oaks (*Quercus mongolica*), with other hardwood trees such as elm (*Ulmus parvifolia, U. davidiana* var. *japonica*), *Carpinus laxiflora*, hazel (*Corylus teterophylla* var. *thunbergii*), lime (*Tilia amurensis*), and maple (*Acer palmatum*) (Fig. 3c).

Deciduous broadleaved forest (DBF) is distributed between 35˚N and 43˚N, except in the subalpine area. The main trees are maples (*Acer palmatum*), oaks (*Quercus dentate, Q. aliena* and *Q. serrata*), birches (*Betula platyphylla* var. *japonica*), *Zelkova serrate, Styrax japonica, Carpinus tschnonoskii, Lindera erythrocarpa, Lindera obtusiloba*, and *Acer mono* (Fig. 3d). This forest is further divided into three zones, the north temperate, central temperate, and south temperate, based on floral components. The north temperate zone of the DBF is distributed from the north central region to the borders of China and Russia. This zone is composed of *Tilia amurnesis* var. *glabrata, Acer tegmentosum, Acer okamotoanum, Betula schmidtii, Quercus mongolica, Corylus sieboldiana, Abies holophylla*, and *Pinus koraiensis*. The central temperate zone of the DBF is distributed south to 40˚N on the east coast, to 39˚N on the west coast, and to 38˚N in the central area and consists of *Zelkova serrata, Strax japonica, Quercus mongolica, Q. serrata, Q. aliena, Lindera obtusiloba, Juniperus chinensis, Abies holophylla*, and *Pinus densiflora*. The south temperate zone of the DBF develops between 35˚N and 36˚N and ranges to 38˚N on the east coast and to 37˚30′N on the west coast. This zone is characterized by the predominance of deciduous broadleaved trees of *Carpinus tshonoskii, Meliosma oldhamii, Pourthiaea villosa, Acer palmatum, Pterocarya strobilacea*, and *Celtis sinensis*, evergreen broadleaved trees of *Euonymus japonica, E. fortune* var. *radicans*, and *Daphniphyllum macropodum*, and conifers of *Pinus densiflora, P. thunbergii*, and *Cephalotaxus koreana*.

Subtropical evergreen forest is located along the south coast and is limited to 35˚N in inland areas and 35˚30′N in coastal areas, including several islands. The main components are trees such as *Quercus acuta, Q. glauca, Q. myrsinaefolia, Castanopsis cuspidate* var. *sieboldii, Cinnamomum camphora, Machilus thunbergii*, and *Euonymus japonica* and shrubs including *Camellia japonica, Ilex integra, Aucuba japonica*, and *Eurya japonica* (Fig. 3e).

Additionally, coastal conifers such as *Pinus thunbergii* grow along the west, south, and east coasts (Fig. 3f). Salt marshes composed of *Sueda japonica, S. glauca, Salicornia europaea, Salosa komarovii*, and *Phragmites communis* are found in patches along the west and south coasts (Fig. 3g). Some recreational forests, run by the national and local governments, were designed by the afforestation of conifers (Fig. 3h).

(a) Conifer forest (*Pinus densiflora*)

(b) Subalpine conifer (*Abies koreana*)

(c) Mixed coniferous & deciduous broadleaved forest (*Pinus densiflora* & *Quercus mongolica*)

(d) Deciduous broadleaved forest (*Quercus aliena* & *Ulmus davidiana*)

(e) Evergreen deciduous broadleaved forest (*Machilus thunbergii*)

(f) Coastal conifer forest (*Pinus thunbegii*)

(g) Salt marsh (*Phragmites communis* & *Suaeda japonica*)

(f) Afforestation (*Chamaecyparis obtusa*)

Fig. 3. Modern forest types of South Korea.

4. Palynological studies in South Korea

Quaternary palynological studies in Korea have mainly focused on the reconstruction of vegetation and climate change since the last glacial maximum (LGM). In the middle to late 20th century, Korean pollen investigations were carried out in peat or organic-rich soil from coastal wetlands or lagoons (e.g., ., Jo, 1979; Oh, 1971; Park, 1990; Tsukada, 1977; Yi et al., 1996; Yoon, 1997). Subsequently, a number of palynological studies were performed due to increased peat layer recovery from excavations of inland wetland and archaeological sites (e.g., Chung & Lee, 2006; Kim et al., 2001; Seo & Yi, 2001; Yi et al., 2006, 2008a). Attempts were made to reconstruct the natural vegetation history in response to climate change from the peat and wetland samples and to intrepret human-induced changes based on age-controlled pollen profiles, (agriculture and land-use in forests). The palynological studies are shown in Table 1.

Two Holocene pollen analyses are introduced herein: the Paju-Unjeong site is located in the west central area, and the Pyeongtaek site is located in the western coastal area on the Korean Peninsula (Fig. 2).

4.1 Pollen assemblages of the Paju-Unjeong area

Zone UJ10-I (elevation 17.954–18.164 m a.s.l., ca. 8425–4700 cal yr BP) was quantitatively dominated by *Quercus* and *Alnus* together with a few broadleaved deciduous trees of *Fraxinus*, *Ulmus/Zelkova*, *Magnolia*, and *Castanea* and the conifer *Pinus*. The dominant herbs were members of the Cyperaceae, with Gramineae and *Artemisia*. Additionally, accessory trees and shrubs and herbaceous taxa were present throughout this zone. Subzone UJ10-Ia (elevation 17.954–17.984 m a.s.l., ca. 8425–7520 cal yr BP) was characterized by the predominance of hardwood trees of *Quercus* and *Alnus* and herbs of Cyperaceae. The common pollen grains were from trees of *Fraxinus, Ulmus/Zelkova, Magnolia, Salix,* and *Castanea* and herbs of Gramineae and *Ambrosia*. Subzone UJ10-Ib (elevation 17.984–18.164 m a.s.l., ca. 7520–4700 cal yr BP) was dominated by *Quercus*, *Alnus,* and Cyperaceae, which gradually declined, in combination with *Pinus*, *Magnolia*, *Ulmus/Zelkova*, Gramineae, and *Artemisia*. The occurrence of *Pinus* somewhat increased upward within this subzone. Other accessory taxa occurred sporadically.

Zone UJ10-II (elevation 18.164 –18.354 m a.s.l., ca. 4700–2170 cal yr BP) was characterized by the dominance of *Pinus*, *Quercus*, Gramineae (≥35 μm), Gramineae, and Cyperaceae. Common elements included hardwood trees of *Magnolia* and *Buxus* and herbs of *Artemisia* associated with a few *Myrica*, *Carpinus*, *Juglans*, *Ulmus/Zelkova*, *Fraxinus*, *Castanea,* and *Ambrosia*. This zone was defined by a distinct decrease in *Quercus* and *Alnus* deciduous broadleaved trees and an apparent increase in *Pinus* conifers and Gramineae (≥35 μm) and Gramineae herbs toward the top of the zone. *Tilia* was found only within this zone.

Zone UJ10-III (elevation 18.354–18.764 m a.s.l., ca. 2170 cal yr BP–Modern) was conspicuously marked by the growing dominance of *Pinus*, Gramineae (≥35 μm), Gramineae, and Cyperaceae, replacing *Quercus* and *Alnus*, which decreased dramatically. Common taxa were the pollen grains derived from *Magnolia* and *Artemisia*, together with a few *Ulmus/Zelkova*, *Myrica*, *Carpinus*, *Juglans*, *Salix*, *Fraxinus,* and *Castanea*. Pollen grains of *Fagopyrum* and Ericaceae appeared only within this zone. The boundary of the subzone was designated by a sudden increase in *Pinus*, *Fagopyrum*, and *Artemisia* and the first appearance of Ericaceae. Subzone UJ10-IIIa (elevation 18.354–18.534 m a.s.l., 2170 to ca. 440 cal yr BP) featured the predominance of herbs, Gramineae (≥35 μm), and Cyperaceae associated with

Archive	Site	Location	Reference	Age
Lake	Yongrangho	Socho-shi, Gangwon Province	Tsukada (1977), Chang & Kim (1982)	Holocene
	Hyangho	Gangneung-shi, Gangwon Province	Fujiki & Yasuda (2004)	Holocene
	Bangeojin	Ulsan-shi, Gyeongsang Province	Jo (1979), Chang & Kim (1982)	Holocene
	Wolhamji	Buyeo-gun, Chungcheong Province	Chang & Kim (1982)	Holocene
Moor, Bog	Mt. Daeam	Inje-gun, Gangwon Province	Chang et al. (1987), Choi & Koh (1989)	Holocene
	Moojaechi	Ulsan-shi, Gyeongsang Province	Park & Chang (1998), Choi (2001)	Holocene
Wetland	Youngyang Basin	Yongyang-gun, Gyeongsang Province	Yoon & Jo (1996)	Late Pleistocene-Holocene
	Hanam	Hanam-shi, Gyeonggi Province	Yi et al. (2008b)	Late Pleistocene-Holocene
	Paju-Unjeong	Paju-shi, Gyeonggi Province	Yi et al. (2011)	Holocene
Coastal wetland	Imja-do	Shinan-gun, Jeolla Province	Yi et al. (2004)	Holocene
	Cheollipo	Taean-gun, Chungcheong Province	Park (1990), Jang et al. (2006)	Holocene
	Ilsan	Goyang-shi, Gyeonggi Province	Yoon (1997), Yi et al. (2005)	Holocene
	Pyeongtaek	Pyeongtaek-shi, Gyeonggi Province	Oh (1971), Jun et al. (2010)	Holocene
Archaeo-logical site	Sorori	Cheongwon-gun, Chungcheong Province	Kim (2001)	Late Pleistocene
	Unjeonri	Cheonan-shi, Chungcheong Province	Park (2004)	Holocene
	Anyoungri	Tacheon-myeon, Chungcheong Province	Seo & Yi (2003)	Late Pleistocene
	Poonggi	Asan-shi, Chungcheong Province	Yi et al. (2006)	Late Pleistocene
	Yongdong	Naju-shi, Jeolla Province	Chung & Lee (2006)	Late Pleistocene
	Yeanri	Gimhae-shi, Gyeongsang Province	Yi & Saito (2003c)	Holocene
	Cheonggye-cheon	Seoul	Yi et al. (2008a)	Holocene
	Jinju	Jinju-shi, Gyeongsang Province	Chung et al. (2006)	Late Pleistocene
	Piseori	Muan-gun, Jeolla Province	Chung et al. (2005)	Late Pleistocene
Island	Hanon	Seogyuipo-shi, Jeju Province	Chung (2007)	Late Pleistocene

Table 1. List of palynological studies in South Korea.

Pinus, *Quercus,* and Gramineae. *Quercus* pollen gradually decreased, whereas *Pinus*, Gramineae (≥35 μm), and *Artemisia* pollen grains gradually increased toward the upper boundary. Moreover, the pollen grains of *Quercus* and *Alnus* decreased, whereas Gramineae (≥35 μm) and Gramineae increased compared with frequencies in the preceding zone. Subzone UJ10-IIIb (elevation 18.534–18.764 m a.s.l., ca. 440 cal yr BP to Modern) was characterized by *Pinus* and Gramineae (≥35 μm), which were the prominent contributors and occurred in very abundant amounts. This zone was marked by an increase in *Pinus* and an apparent decrease in Gramineae, Cyperaceae, and *Artemisia*. *Quercus* and Gramineae (≥35 μm) were continuously present (Yi, 2011) (Fig. 4).

4.2 Pollen assemblages of the Pyeongtaek area

Zone HS-I (depth 192–187 cm, ca. 10 600 to ca. 10 400 cal yr BP) was dominated by *Quercus* (up to 22%) together with a few broadleaved deciduous trees of *Alnus* and *Betula* and the conifer, *Pinus*. The dominant herbs were members of the Cyperaceae, with a few Gramineae and *Typha*. Additionally, accessory trees and shrubs and herbaceous taxa were present throughout this zone.

Zone HS-II (depth 187–122 cm, ca. 10 400 to ca. 8000 cal yr BP) was defined by a distinct increase in *Quercus* deciduous broadleaved trees and an apparent decrease in Cyperaceae herbs. Arboreal pollen indicated that conifers of *Pinus* and *Larix* and deciduous broadleaved trees such as *Carpinus*, *Juglans*, *Ulmus*/*Zelkova*, and *Alnus* increased slightly from the preceding zone. Chenopodiaceae showed an increasing trend, whereas Cyperaceae decreased throughout the zone. Gramineae was still common in this zone. The pollen concentration of all taxa decreased compared with that in the preceding zone.

Zone HS-III (depth 122–77 cm, ca. 8000 to ca. 6000 cal yr BP) was characterized by the sudden expansion of T-C-C (Taxaceae-Cephalotaxaceae-Cupressaceae) and Cyperaceae compared with zone HS-II. *Quercus* declined in frequency and gradually decreased toward the top of the zone. Chenopodiaceae decreased to the point of being rare in this zone. Gramineae slightly increased. The pollen concentration varied among samples (average 380 000 grains/g) but was relatively high, reaching 1 000 000 grains/g.

Zone HS-IV (depth 77–44 cm, ca. 6000 to ca. 4500 cal yr BP) was marked by the predominance of *Alnus* and T-C-C associated with *Quercus*, Gramineae, and *Typha*. Fern spores increased in frequency, with greater numbers toward the top of the zone. Freshwater algae and aquatic pollen were common. This zone showed the highest pollen concentration (average 500 000 grains/g) among the pollen zones (Jun et al., 2010) (Fig. 5).

5. Vegetation change and the East Asian monsoonal fluctuation in South Korea during the Holocene Period

5.1 Vegetation changes

The available age-controlled pollen datasets allow us to infer the vegetational history of South Korea. The vegetation changes in the eastern and western parts of South Korea are discussed. During the early Holocene (10 000–7000 cal yr BP), subalpine conifer forest was replaced by broadleaved deciduous forest dominated by hardwood oak trees due to climatic amelioration. Moreover, the forest components evidenced by the pollen records are greater than those of the preceding period. During the mid-Holocene optimum, the former forest was replaced by a mixed subtropical and warm-temperate broadleaved forest, which was characterized by evergreen oak and thermophilous hardwood trees. These trees were composed mainly of oak

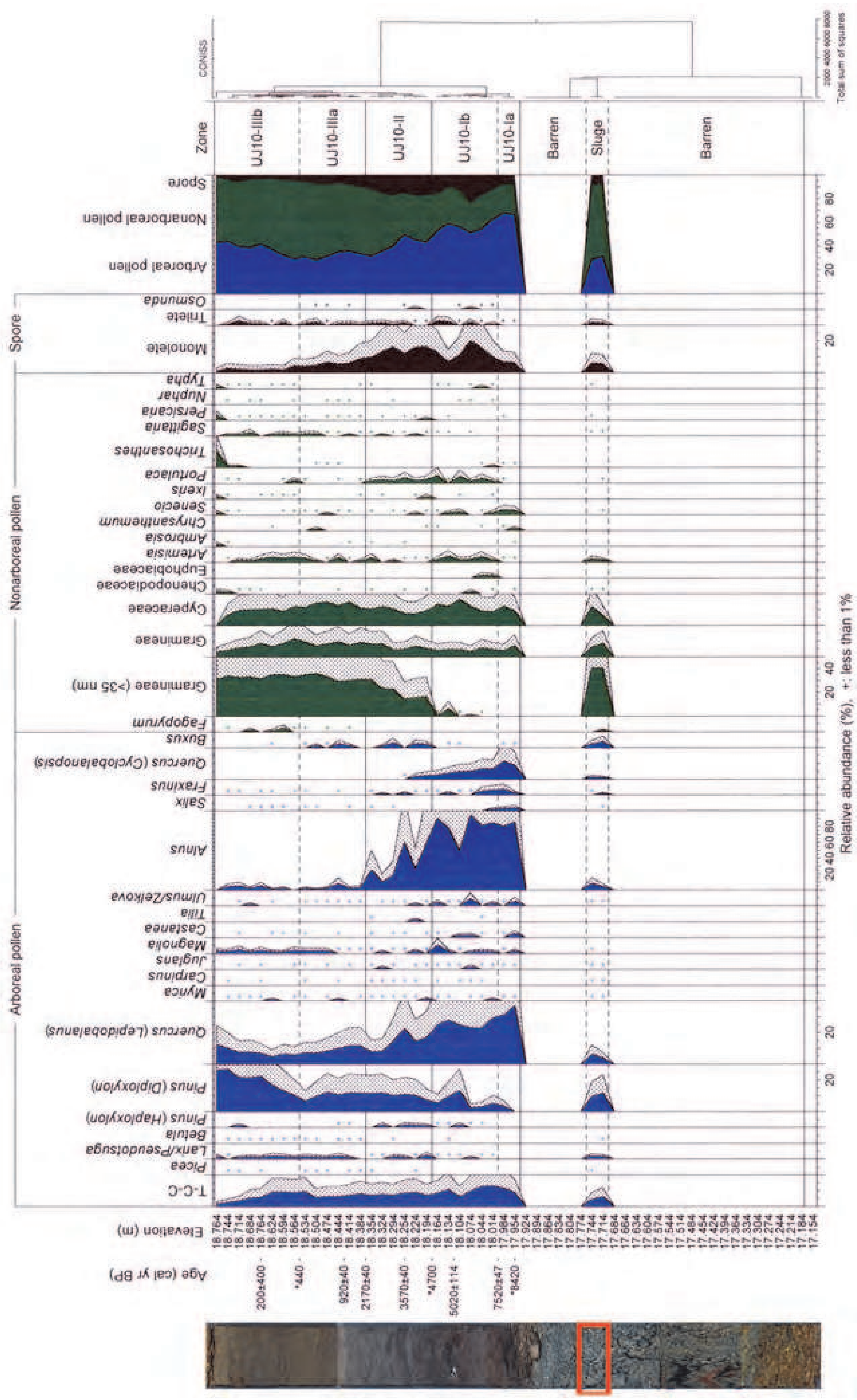

Fig. 4. Pollen diagram of selected taxa with the pollen zones of core UJ10 of the Paju-Unjeong area (modified from Yi, 2011).

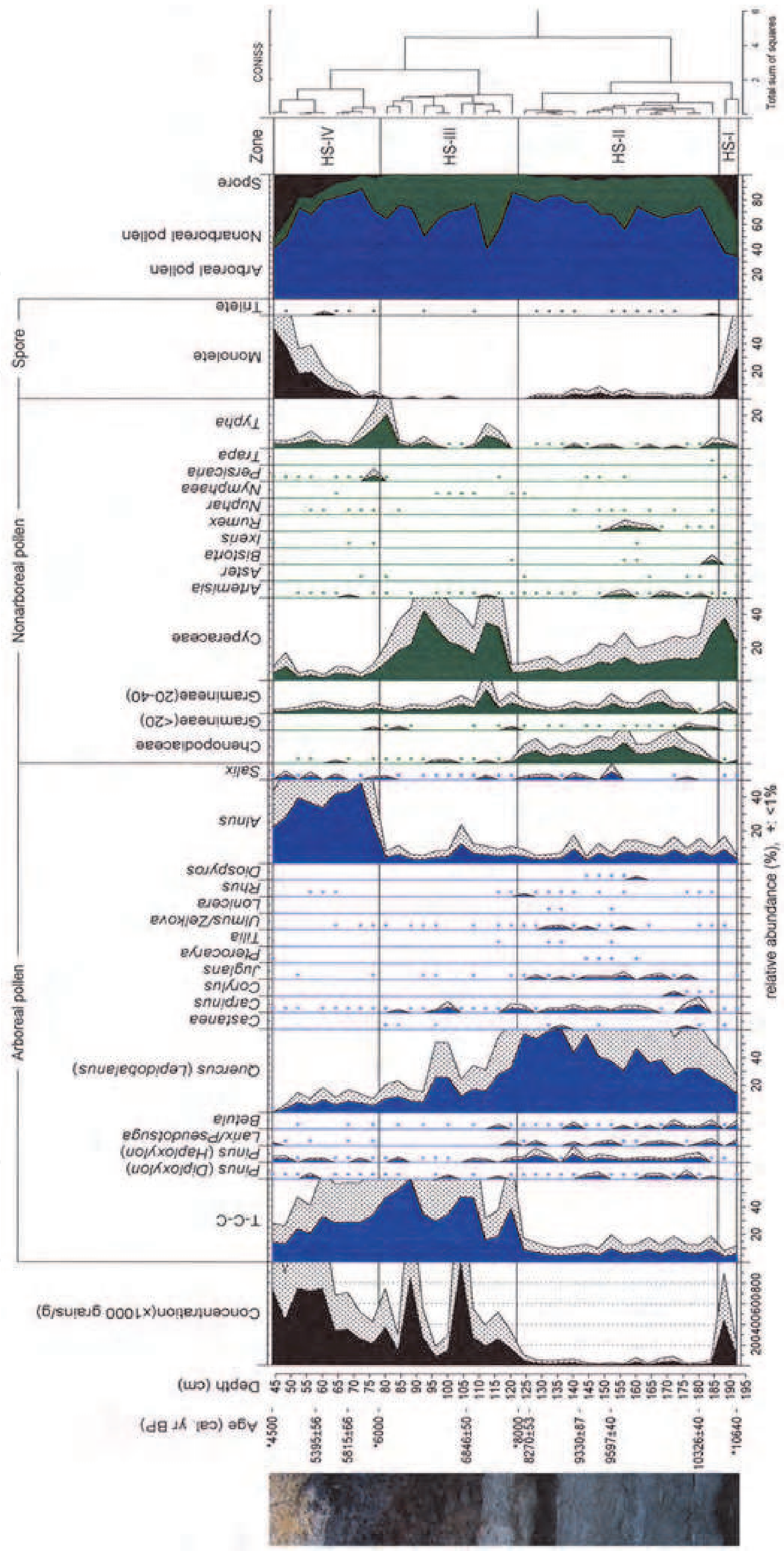

Fig. 5. Pollen diagram of selected pollen taxa with pollen zones of Hwangsan Trench in the Pyeongtaek wetlands (modified from Jun et al., 2010).

[*Quercus* (*Cyclobalanopsis*)] and *Q.* (*Lepidobalanus*)], hornbeam (*Carpinus*), hazel (*Corylus*), alder (*Alnus*), zelkova (*Zelkos*), and elm (*Ulmus*). The mixed subtropical and warm-temperate broadleaved forest flourished under the favorable warm and wet climatic conditions. After the mid-Holocene optimum, the subtropical and warm-temperate forest shrank and was replaced by a temperate forest due to climatic deterioration. Beginning about 2000 cal yr BP, the forest was affected by human impacts, such as cultivation, slash-and-burn agriculture, and deforestation, recorded in the pollen by the first appearance of the agricultural indicator buckwheat (*Fagopyrum*) in association with sudden increases in synanthropogenic indicators [*Ambrosia*, *Plantago*, *Artemisia*, and Gramineae (≥35 μm)] and secondary pine trees (Fujiki & Yasuda, 2004; Jo, 1979; Tsukada, 1977).

Compared with the east coast, pollen studies from the west coast are more numerous (e.g., Jang et al., 2006; Jun et al., 2010; Oh, 1971; Park, 1990, Yi et al., 2005; Yi et al., 2010; Yoon, 1997) because there are a plenty of wetlands along this coast. From 8000 to 5000 cal yr BP, subtropical evergreen and warm-temperate forest occupied this area, especially the hills and low mountainous areas, resulting in a high proportion of pollen from trees and shrubs with a smaller proportion from herbs. The evergreen and warm-temperate forest consisted mainly of oak [*Quercus* (*Cyclobalanopsis*)] and *Q.* (*Lepidobalanus*)], alder (*Alnus*), willow (*Salix*), hornbeam (*Carpinus*), hazel (*Corylus*), zelkova (*Zelkos*), and elm (*Ulmus*). However, Jun et al. (2010) pointed out that salt marsh (*Suaeda*) pollen appeared only at certain periods that were comparable to transgression periods of the Yellow Sea (Chough et al., 2004; Park, 1992). The favorable conditions characterized by high moisture and warmer temperatures during the mid-Holocene optimum and the transgression of the Yellow Sea accelerated the flourishing of forests along the western region. Later, the forest was replaced by conifer-dominated forest with an herb-dominated understory until about 2000 cal yr BP. Additionally, the components of the hardwood forests showed a sudden decline in alder (*Alnus*) and an increase in birch (*Betula*) and hazel (*Corylus*) owing to climatic deterioration. Beginning about 2000 cal yr BP, anthropogenic indicators, including *Fagopyrum*, *Ambrosia*, *Plantago*, *Artemisia*, and Gramineae (≥35 μm), and pine trees indicate that human activity played an important role in disturbing the forest and in secondary forestation.

Korea Meteorological Administration (KMA) reports that there was a mean annual temperature of 12.2℃ and 1255 mm in a mean annual precipitation during the 1973–1980, but the temperature and precipitation increased up to 12.9℃ and 1469 mm, respectively, between 2001 and 2007. This meteorological phenomena show the climate conditions of Korea are changing to be subtropical zones caused by global warming. With such climate conditions, types and communities of Korean forest can be expected to change. For example, a Korean fir (*Abies koreana*), which is a sensitive to temperature, cannot be survived any longer in high mountains, such as Mt. Halla in Jeju Island, Mt. Duckyoo in central region and Mt. Seolak in eastern region. Moreover, north limit of vegetation distribution will migrate northward. Evergreen broadleaved forests may widely distribute and expand north to about 37°N as they did during the mid-Holocene pollen record (e.g., Jang et al., 2006; Yi et al., 2008). The distribution of both a coniferous forest and a mixed forest of conifer and deciduous broadleaved tree will be reduced. South temperate zone of deciduous broadleaved forest (DBF) will replace the central temperate zone of DBF in South Korea (Fig. 2).

In summary, the Holocene pollen records reflect differences in forest plant assemblages between the western and eastern regions during the early to middle Holocene. In the eastern coastal area, dominance alternated between oak and pine over time, reflecting climate changes during the early to middle Holocene. However, in the western coastal area, oak and alder were co-dominant taxa during the early to middle Holocene. This is a reflection of the geomorphic features of and the marine environmental influence over the Korean Peninsula. The Korean Peninsula is geomorphologically highly mountainous in the east and flat, low, and wide in the west (Fig. 2). During the early to middle Holocene, the west coast experienced wetter conditions for a longer period of time than did the east coast during sea-level rise. From the late Holocene (ca. 2000 cal yr BP), pine trees and agricultural indicators increased over South Korea, reflecting the intensity of human impact since that time (Fig. 6). Due to global warming, no subalpine conifer, especially a Korean fir (*Abies koreana*), will be exist in South Korea in near future. Also evergreen broadleaved forest will further spread north to 37°N, and south temperate zone of DBF will occupy the region of central temperate zone of DBF.

5.2 Vegetation responses to turbulent East Asian monsoonal changes during the early to middle Holocene

About 9000 cal yr BP, the concentration of CO_2 (up to 380 ppm) reached a maximum in the atmosphere along with increased solar radiation in the Northern Hemisphere in the summer (Berger, 1978; Neftel et al., 1982). In July, solar radiation was 7% higher than at present. As a result, the seasonal range of temperatures was considerably increased. The difference in warming between the continent and ocean was higher, leading to monsoons (Kutzbach, 1981; An et al., 2000; Shi et al., 2011). The majority of thermophiles, particularly evergreen trees, did not grow well because of cold winters, even though summers were relatively warm. This is why deciduous oak forests were so common in South Korea during the early Holocene.

From the mid-Holocene optimum, the percentage of broadleaved deciduous components gradually decreased, whereas the percentage of pollen grains from evergreen oak [*Quercus* (*Castanopsis*)] increased (Fig. 7). During that time, deciduous broadleaved forests were replaced by evergreen forests mostly composed of *Q*. (*Castanopsis*). The climate became milder, with warmer winters. More proportional solar radiation per season (Fig. 7) led to a decreased annual range of temperatures: July temperatures slightly decreased, and January temperatures increased. It is possible that there was related adaptation to a slightly warmer winter climate. The range of deciduous oak forests shrank in this region, probably due to increased moisture. Mean annual temperature in Korea (Sohn, 1984) was 2–3℃ higher than presently. Temperature differences between the northern and southern parts of the Korean Peninsula remarkably increased toward the end of this phase (Sohn, 1984). An enhanced summer monsoon provided favorable conditions to an evergreen oak–dominated forest.

Pollen studies in China indicate that forest vegetation occupied a larger area during the mid-Holocene (Yu et al., 1998, 2000) due to warm and wet climate together with greater than present summer insolation and stronger Pacific monsoon activity (Winkler & Wang, 1993). The oak-pine woodland and steppe were replaced by a dry steppe vegetation in northeast China region after late Holocene of ca. 3500 cal. yr BP (Liu et al., 2002; Tarasov et al., 2006).

Takahara et al. (2000) concluded that the vegetation distribution at mid-Holocene time (6000 yr BP) was rather similar to present. From their pollen study, they pointed out the broadleaved evergreen and warm mixed forest may have been present at higher elevations in the mountains of central Japan. But, the northern limit of the biome was apparently similar to present as a consequence of northward migration of the biome under warmer and wetter conditions.

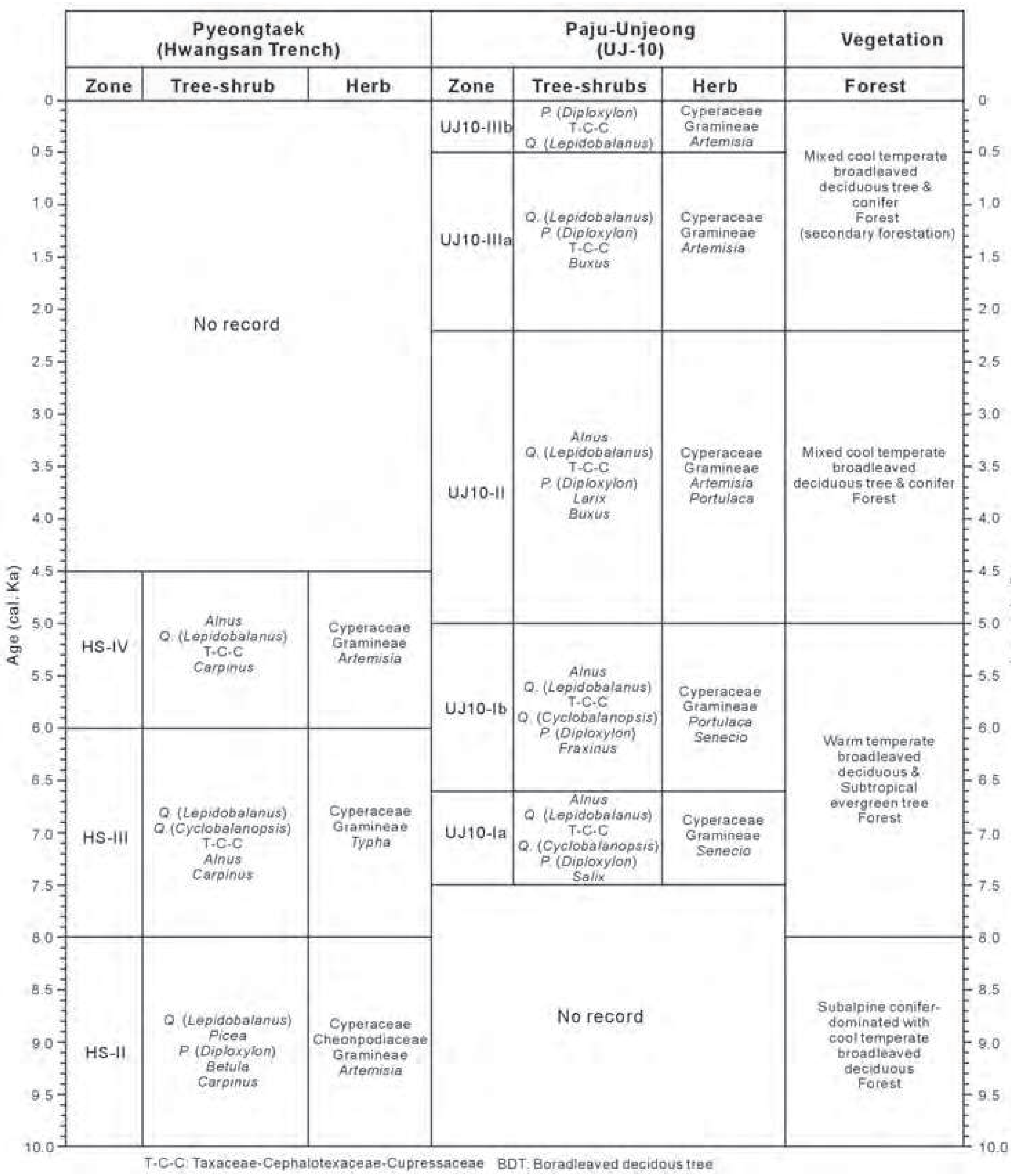

Fig. 6. Correlation of pollen zones, with main trees and herbs, between the Pyeongtaek and Paju-Unjeong areas and forest history during the Holocene period (compiled from Jun et al., 2010 and Yi et al., 2011).

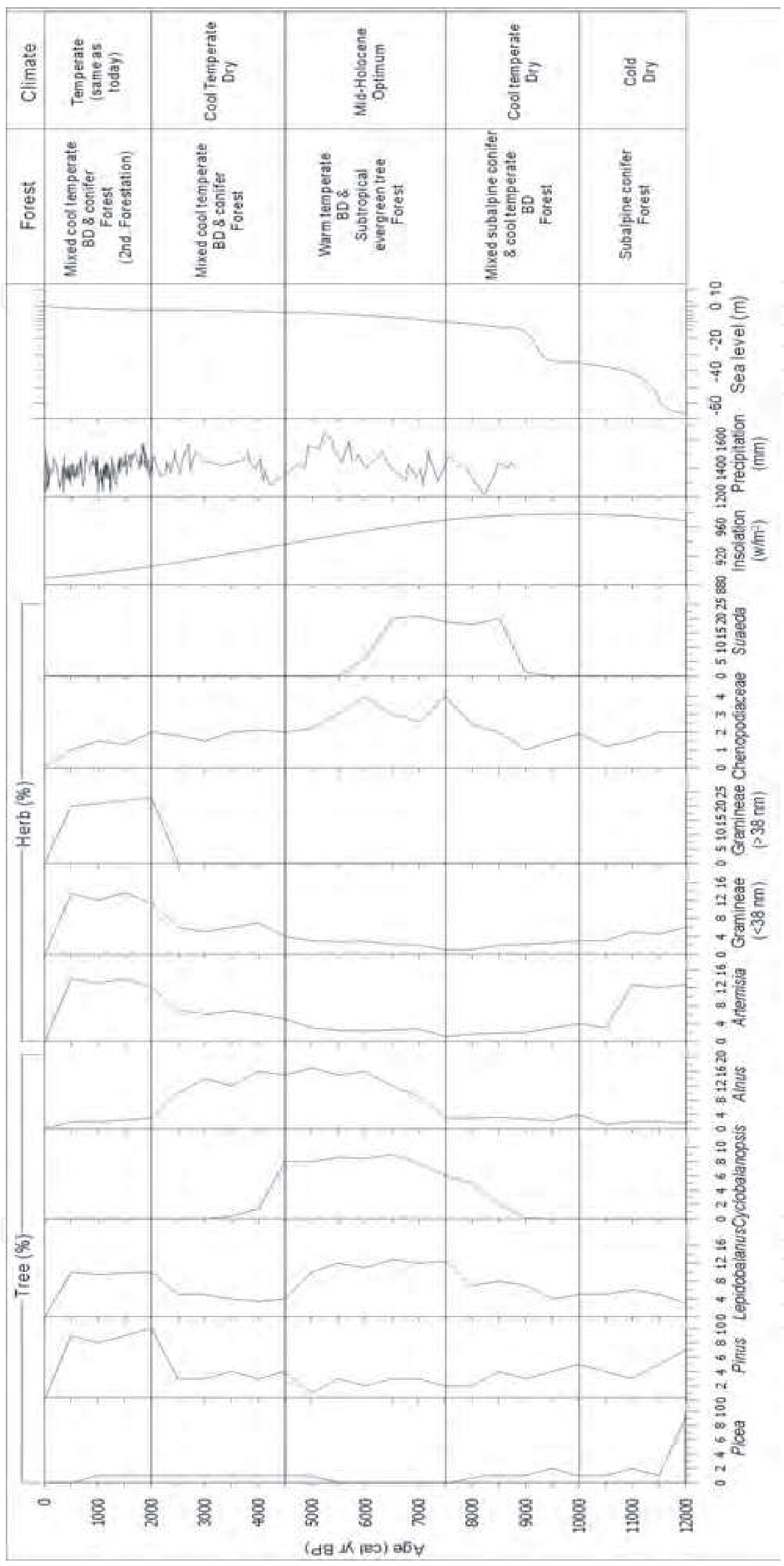

Fig. 7. Vegetation and climate changes based on pollen indicators in South Korea during the Holocene period. Insolation (July), precipitation, and sea level are from Berger (1978), Hu et al. (2008), and Park (1992) and from Chough et al. (2004), respectively. BD: Broadleaved deciduous

6. Conclusion

The Korean Peninsula, surrounded by the sea on three sides (east, west, and south), is located on the eastern end of the Asian continent and belongs to the temperate zone with four distinct seasons largely controlled by the East Asian monsoon. During the summer, the Korean Peninsula is occupied by a subtropical high pressure system and experiences warm, wet conditions with frequent, heavy rainfalls. During the winter, it is cold and dry under the dominant influence of the northwesterly Siberian high air mass. The Korean Peninsula is an area sensitive to climate changes. Therefore, well-preserved records from the Korean Peninsula that provide a continuous climate history are a source of valuable information of the East Asian monsoonal system.

Age-controlled pollen stratigraphy was obtained from several organic-rich sediments in wetlands and archaeological sites in South Korea. Holocene vegetation and climate were deduced from pollen records. During the Early Holocene (ca. 10 400−8000 cal yr BP), dry, cool-temperate conditions encouraged *Quercus*-dominated deciduous broad-leaved forests with conifers (*Pinus*) and cool-tolerant birch (*Betula*) in the hills and mountainous areas as post-glacial warming began. A mid-Holocene climate optimum occurred between 7000 cal yr BP and 5000 cal yr BP, when evergreen broadleaved oak [*Quercus* (*Cyclobalanopsis*)] and deciduous broadleaved hardwood trees flourished and migrated northward to the central Korean Peninsula (N 37-38°), while conifers and cool-tolerant birch (*Betula*) retreated higher up the mountains. After the mid-Holocene (ca. 5000 to ca. 3000 cal yr BP), evergreen and deciduous broadleaved *Quercus*-dominated forests were replaced by mixed conifer and deciduous broadleaved forests due to climatic deterioration to dry, cool-temperate conditions. During the late Holocene (ca. 3000−2000 cal yr BP), mixed coniferous and deciduous broadleaved forests were continuous in the mountainous areas under wet, cool-temperate climatic conditions. Since 2000 cal. yr BP, forests were primarily affected by human disturbance in Korea. That is, sterilized mountain soil conditions caused by human activity such as deforestation and cultivation accelerated the expansion of coniferous forest, replacing the former mixed-vegetation forest. Human impact is indicated by the occurrence of cultivated plants, Gramineae (≥35 μm), and buckwheat (*Fagopyrum*) combined with synanthropogenic *Ambrosia* and *Artemisia*.

Owing to global warming, no subalpine conifer, especially a Korean fir (*Abies koreana*), will be exist in South Korea in near future. Also evergreen broadleaved forest will further spread north to N 37°, and south temperate zone of deciduous broadleaved forest will occupy the region of central temperate zone of deciduous broadleaved forest.

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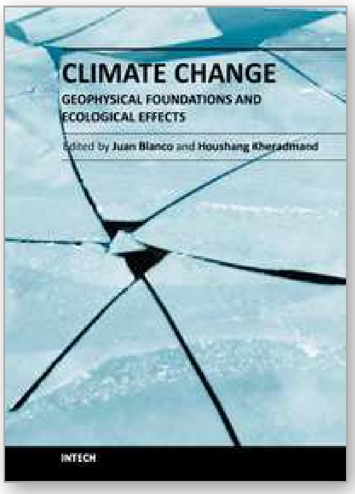

Climate Change - Geophysical Foundations and Ecological Effects
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This book offers an interdisciplinary view of the biophysical issues related to climate change. Climate change is a phenomenon by which the long-term averages of weather events (i.e. temperature, precipitation, wind speed, etc.) that define the climate of a region are not constant but change over time. There have been a series of past periods of climatic change, registered in historical or paleoecological records. In the first section of this book, a series of state-of-the-art research projects explore the biophysical causes for climate change and the techniques currently being used and developed for its detection in several regions of the world. The second section of the book explores the effects that have been reported already on the flora and fauna in different ecosystems around the globe. Among them, the ecosystems and landscapes in arctic and alpine regions are expected to be among the most affected by the change in climate, as they will suffer the more intense changes. The final section of this book explores in detail those issues.