



Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Palynological implication of Holocene vegetation and environment in Pyeongtaek wetland, Korea

Chang Pyo Jun^a, Sangheon Yi^{b,*}, Seong Joo Lee^a

^aDepartment of Geology, Kyungpook National University, Daegu 702-701, Republic of Korea

^bGeologic Environment Division, Korea Institute of Geoscience and Mineral Resources, Daejeon 305-350, Republic of Korea

ARTICLE INFO

Article history:

Available online 10 June 2010

ABSTRACT

Vegetational and depositional environmental changes were interpreted from a trench in ca. 10 000 cal BP sediments in the Pyeongtaek wetland, Korea, based on palynomorph and grain size analysis. From ca. 10 400–8000 cal BP, cool, dry, temperate conditions encouraged *Quercus*-dominated deciduous broadleaved forest, with conifers and cool-tolerant birch prevailing on hills and in mountainous areas as postglacial warming began. Halophytic Chenopodiaceae pollen and marine dinoflagellates indicate the depositional environment was an intertidal flat. Conditions became warm and wet between ca. 8000 and ca. 6000 cal BP: areas still contained *Quercus*-dominated deciduous broadleaved forest but with decreased conifers and cool-tolerant birch. The absence of marine dinoflagellates and abundant meso- to hypersaline salt marshes of Gramineae, with a later increase of mesosaline Cyperaceae marshes, indicate a transition from intertidal flat to freshwater swamp. From ca. 6000 to ca. 4500 cal BP, *Quercus*-dominated forests were replaced by mixed conifer–deciduous broadleaved forests under climatic deterioration. Aquatic genera and freshwater algae indicate that the study area completely changed to freshwater swamp. The directional sequence in relative abundance of taxa (maximum percentage of pollen of Chenopodiaceae followed by Gramineae, Cyperaceae, and aquatics) suggests a gradational pattern indicative of marked environmental clines typical of intertidal habitats.

© 2010 Elsevier Ltd and INQUA. All rights reserved.

1. Introduction

Vegetation dynamic reconstruction based on high-resolution pollen analysis is an important tool to improve understanding of climate change and local environmental changes. To achieve such reconstructions, however, requires investigation of the mechanisms underlying the responses of temperate ecosystems to climate changes. In addition, an understanding of the ecological response of terrestrial plants to climate changes is required to get realistic feedbacks between climate and the biosphere and to validate paleoclimate reconstruction.

The East Asian monsoon-controlled coastal area is an open system that experiences an intensive interplay between oceanic and terrestrial processes. The ecological response of sensitive terrestrial ecosystems can provide independent data complementing the almost exclusively marine body of evidence. Therefore, coastal—especially intertidal—ecosystems can provide valuable information on past depositional environmental changes, because such

systems are very sensitive to environmental changes in the sea–continent interface (Byrne et al., 2001; Crain et al., 2004; Malamud-Roam and Ingram, 2004; González and Dupont, 2009).

The Pyeongtaek wetland, whose name means “flat swamp”, is a wide flat paleo-swamp formed during the early Holocene (Lee, 2003; Ryu et al., 2007). The Pyeongtaek wetland is located near the central part of the west coast of the Korean Peninsula, and as it was formed during the early Holocene, this area can be particularly useful for investigating coastal plant community ecological responses to climate change and sea-level fluctuations. This study attempted to reconstruct the Holocene vegetation and depositional environment of the Pyeongtaek area in response to climate changes, based on age-controlled pollen-spores and phytoplanktonic algae records.

2. Study area

The Korean Peninsula is within a temperate climatic zone controlled by East Asian monsoons. During the summer, the peninsula experiences a subtropical high-pressure system with warm and wet conditions and frequent heavy rainfall events. During the winter, the dominant influence of the northwesterly Siberian high air mass makes the weather cold and dry.

* Corresponding author. Fax: +82 42 861 9714/+82 42 868 3414.
E-mail address: shyi@kigam.re.kr (S. Yi).

Pyeongtaek is located near the central part of the west coast of the Korean Peninsula (Fig. 1). The Hwangsan Trench ($36^{\circ}57'25''\text{N}$, $126^{\circ}55'52''\text{E}$) was excavated in 2005 in the southern part of the Pyeongtaek wetland, which is now used as paddy fields for rice cultivation. Geomorphologically, Pyeongtaek is a wide flat wetland surrounded by low hills with elevations of 20–50 m above sea level. The wetland sediments were deposited by the Anseong River and its tributary streams flowing toward the south and southwest. The Dodae tributary, passing through the Anseong River, flows westward into the Yellow Sea. Asan Bay, which is fed by the Anseong River of 40 km long and 2.2 km wide, penetrates deeply into the land. Before the construction of a tide embankment in 1973, the Anseong River was influenced daily by a semidiurnal tide, with a mean tidal range of 6.1 m (max. 9.6 m).

At present, the Pyeongtaek area experiences a cool temperate climate. The area is characterized by a mean annual temperature of 11.6°C , with temperatures ranging from a high of 25.9°C in August to a low of -3.0°C in January, between 1971 and 2000 (Korea Meteorological Administration, <http://www.kma.go.kr>). Precipitation is relatively high (mean 1228.9 mm), and about 65% of the annual precipitation falls in the summer, especially June–August.

According to the classification model of Mitsch and Gosselink (2000), Pyeongtaek is classified as a coastal wetland consisting mainly of a clay-and-sand plain. Today, vegetation of this area is characterized by hygrophilous grasses and shrubs, such as reed

(*Phragmites australis*), wild rice (*Zizania latifolia*), bulrush (*Typha orientalis*), and wild rye (*Salix gracilistyla*). In addition, trees of Japanese black pine (*Pinus thunbergii*), oaks (*Quercus serrata*, *Q. variabilis*, *Q. dentata*, and *Q. aliena*), elm (*Zelkova serrata*), and chestnut (*Castanea crenata*) grow on the hills and surrounding mountains (KIGAM, 2005).

3. Materials and methods

The Hwangsan Trench lies on a wide flat wetland adjacent to low hills. The Holocene tidal and swamp deposits studied here were estimated to be 3 m thick. The sediments are mainly composed of (in ascending order) silt, organic-rich mud, and peat with plant fragments and appear to have been formed in a back swamp of the Anseong River.

For palynological analysis, 38 undisturbed samples were taken at 4-cm intervals from depths of 44–192 cm (elevation 3.932–5.412 m) in the Hwangsan Trench. 10 g of sample was used for palynological analysis. Standard palynological preparation techniques (Moore et al., 1991) were used. Three exotic *Lycopodium* spore tablets were added to each sample before further preparation to estimate the palynological concentration (Stockmarr, 1972). HCl (30%) was used for dissolving calcareous minerals, and HF (45%) treatment was used to remove siliceous materials. The organic matter recovered was separated from undigested mineral detritus



Fig. 1. A map showing the site of the Hwangsan Trench (HS) within the Pyeongtaek wetland.

using $ZnCl_2$ (specific gravity 2.0), and acetolysis was used to remove cellulose and humic debris. The residues were strewn-mounted on glass slides using glycerin jelly. Palynomorph identification was aided by the use of published works with illustrations (Chang and Rim, 1979; van Geel et al., 1981, 1982, 1989; Mudie and Harland, 1996). Palynomorphs were counted (up to 400 grains per slide) with an optical microscope, mostly at 400x magnification, except when difficulty in identification required a higher magnification of 1000x. Only the principal pollen and spores were included in the percentage palynological diagram. The percentages of arboreal pollen, non-arboreal pollen and spores were calculated from the total palynomorph sum, excluding algae. Raw data were converted into percentages using TILIA v2.0 (Grimm, 1993). TILIAGRAPH v1.25 (Grimm, 1991) was used to generate the palynological diagram, which was subdivided into palynological zones, using constrained cluster analysis (CONISS) (Grimm, 1987). Pollen taxa used to generate the zonation dendrogram included arboreal pollen and non-arboreal pollen with values of at least 2% in two intervals.

Chronological control was provided by ^{14}C AMS radiocarbon dates. Dating was mainly carried out on peat and bulk organic-rich sediments. AMS dating of six samples was conducted by the National Center for Inter-University Research Facilities of Seoul National University, Korea, and one was done by Geochron Lab, Krueger Enterprises, Inc., USA.

4. Results

4.1. Stratigraphy

In the Hwangsang Trench, basal sediments from 1.912 to 3.932 m a.s.l. were relatively hard brown mud deposits, believed to be late Pleistocene and found widely along the west coast of the Korean Peninsula (Lim and Park, 2003). A uniformly thin dark-gray mud and thick greenish light-gray mud with abundant plant fragments overlaid the hard brown mud. Intercalated within the greenish light-gray mud were deposits of peat between 4.5 and 4.6 m a.s.l. Finally, these sedimentary layers were overlain by a conspicuous

thick peat layer with faint laminations (4.8–5.3 m a.s.l.). The parts of the sequences above the hard brown mud layer are the focus for this study because of their presumed Holocene origin (Fig. 2).

4.2. Chronology

Seven samples were dated using the AMS radiocarbon technique (Table 1). Most of the radiocarbon dates appeared in stratigraphic order. Calibrate ages (cal BP) were obtained at the 2σ confidence level using the CalPal-2007 online program by Danzeglocke et al. (2009) with CalPal-2007_{Hulu} calibration data (Weninger and Jöris, 2008). The age–depth model is based on a combination of calibrated ages from the seven radiocarbon dates and was constructed by linear regression ($R^2 = 0.975$; Fig. 2). The ages indicate that the studied section was deposited from 10 640 to 4550 cal BP, encompassing the early to middle Holocene. All dates relating directly to this study are hereafter referred to in the calibrated form (cal BP) of the midpoint of the 2σ range. Dates arrived at by interpolation or extrapolation from the relevant age–depth relationship are prefixed with “ca”.

4.3. Palynological zone and its characteristics

The abundance in the palynological diagram was sufficient to reveal underlying trends in the site's vegetation history. In the following, pollen counts are expressed as percentages of the total palynological sum. The principal pollen taxa observed were those of trees (*Quercus*, *Alnus*, and Taxaceae-Cephalotaxaceae-Cupressaceae [T-C-C]) and herbs (Cyperaceae, Chenopodiaceae, Gramineae, and *Typha*). Fern spores, freshwater algae, and marine dinoflagellates were also present, but the marine dinoflagellates occurred only in the lowest stratigraphic section. The palynological profile was divided into four local palynological assemblage zones (HS-I–HS-IV) based on statistical analysis (CONISS) and significant changes in principal taxa (Fig. 3). Ages of local palynological assemblage zone boundaries were also established by interpolation using the age–depth curve.

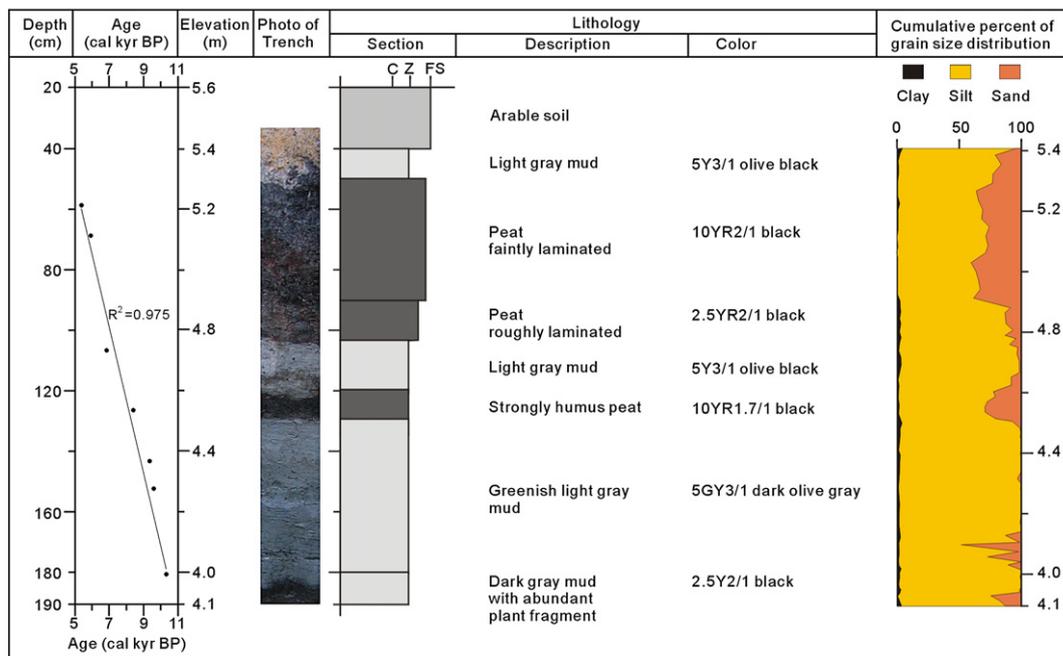


Fig. 2. Photo of the trench with corresponding depth, calibrated age, elevation, and lithologic characteristics. Sediment compositions are well correlated with variations in the cumulative percent of grain size distribution. C: clay, Z: silt and FS: fine sand.

Table 1

AMS radiocarbon dates of the Hwangsansan Trench profile from the Pyeongtaek wetland, Korea. Calibrated ages are recalculated by CalPal-2007online (Danzeglocke et al., 2009).

Depth (cm)	Elevation (m)	Materials	Conventional ¹⁴ C age (yr BP)	Calibrated age (cal. yr BP)	δ ¹³ C (‰)	Laboratory code
58	5.272	Sediment bulk	4650 ± 40	5395 ± 56	-19.67	SNU05-359
68	5.172	Sediment bulk	5060 ± 50	5815 ± 66	-29.00	GX32143
106	4.792	Sediment bulk	6000 ± 40	6845 ± 50	-32.07	SNU05-355
126	4.592	Sediment bulk	7440 ± 40	8270 ± 53	-60.26	SNU05-357
142	4.432	Sediment bulk	8320 ± 60	9330 ± 87	-29.65	SNU05-358
152	4.332	Sediment bulk	8630 ± 40	9597 ± 40	-30.12	SNU05-351
180	4.052	Sediment bulk	9160 ± 40	10 326 ± 40	-40.45	SNU05-352

SNU: Seoul National University.

GX: Geochron Lab., Krueger Enterprises, Inc. USA.

Zone HS-I (depth 192–187 cm, ca. 10 600 to ca. 10 400 cal BP) was dominated by *Quercus* (up to 22%) together with a few broadleaved deciduous trees of *Alnus* and *Betula*, and conifer, *Pinus*. The dominant herbs were members of the Cyperaceae, with a few Gramineae and *Typha*. In addition, 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 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. Marine dinoflagellates were abundant, together with the common freshwater green colonial alga *Pediastrum* and zygospores, namely *Spirogyra* and *Zygnema*. The palynological concentration of all taxa obviously decreased as compared to that in the preceding zone.

Zone HS-III (depth 122–77 cm, ca. 8000 to ca. 6000 cal BP) was characterized by the sudden expansion of T-C-C and Cyperaceae as compared to zone HS-II. *Quercus* conspicuously 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 increases. Freshwater algal spores were still present, but marine dinoflagellates were absent. The palynological

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 BP) was marked by the predominance of *Alnus* and T-C-C associated with common *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 palynological concentration (average 500 000 grains/g) among the palynological zones.

5. Discussion

5.1. Early to middle Holocene vegetation history and inferred climate changes

The palynological record from tidal and swamp deposits of the Pyeongtaek area reveals a dynamic vegetation response to climate changes during the early to middle Holocene. Palynological assemblages of the Hwangsansan Trench typically contain 38–79% arboreal pollen, 20–64% non-arboreal pollen, and 1–40% fern spores. The palynological zones show fluctuations in the frequencies of the principal pollen taxa, reflecting distinct vegetation changes.

During certain periods, pollen grains derived from *Alnus* and T-C-C appeared to be overrepresented in the palynological diagram (Fig. 3). These trees are primarily controlled by local surface

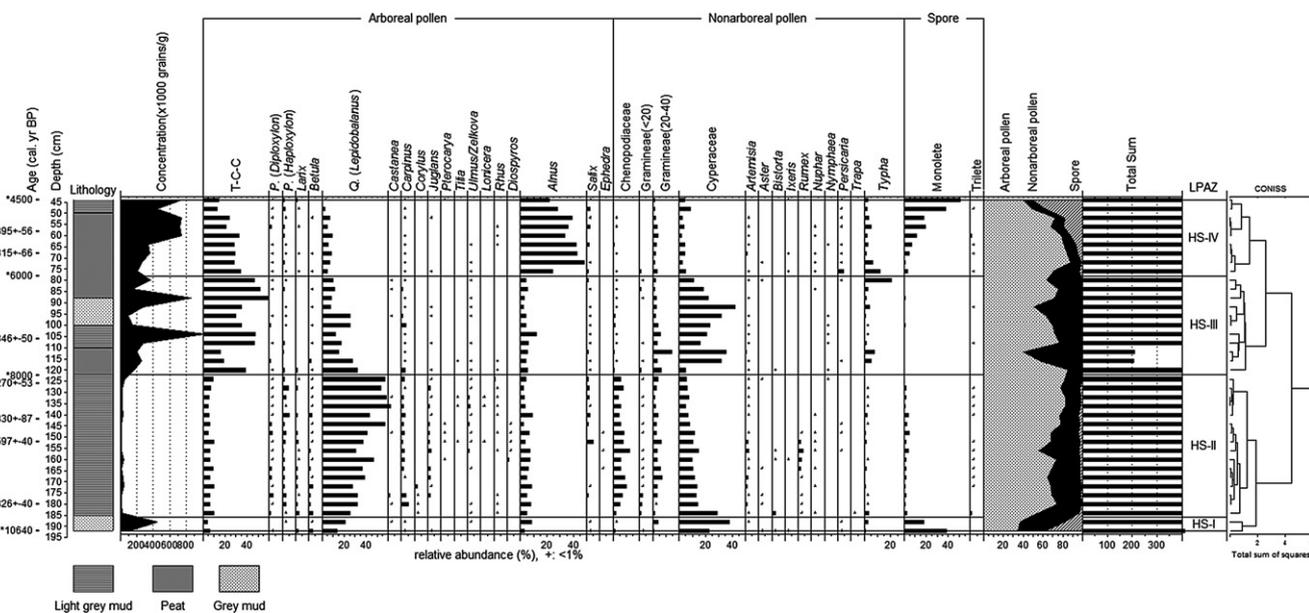


Fig. 3. Palynological diagram of the Hwangsansan Trench in the Pyeongtaek wetland. Calibrated radiocarbon dates are shown on the left of the diagram. The dendrogram on the right was generated by constrained cluster analysis with CONISS. Asterisks indicate age determinations of palynological boundaries, as calculated by interpolation or extrapolation using the in age–depth curve in Fig. 2. T-C-C: Taxaceae-Cephalotaxaceae-Cupressaceae, *P.* (*Diploxylon*), *P.* (*Haploxylon*); *Pinus* (*Diploxylon*), *P.* (*Haploxylon*); *Q.* (*Lepidobalanus*); *Quercus* (*Lepidobalanus*).

environments rather than regional climatic conditions (Traverse, 1988). An extremely high proportion of these pollen grains affects the display of the relative frequencies of some critical species and may lead to misinterpretation of vegetation types and their dynamic responses to climate changes. Therefore, these locally dominant taxa were excluded in order to reconstruct a more accurate vegetation history of the Pyeongtaek wetland (Fig. 4).

During the early Holocene (ca. 10 400 to ca. 8000 cal BP), the predominance of *Quercus* (oak) together with common *Carpinus* (hornbeam) and *Juglans* (walnut) suggests that a *Quercus*-dominated, cool temperate, deciduous broadleaved forest flourished on the adjacent hills or mountainous area. Conifers, such as *Pinus* (pine) and *Larix* (larch), and cold-tolerant *Betula* (birch) were also common. The frequency of *Quercus* pollen remained constant over this period, whereas that of conifers and cool-tolerant *Betula* slightly decreased upward. These findings indicate the following vegetation dynamics: the conifer-dominated forests with some cool deciduous broadleaved trees were succeeded by *Quercus*-dominated forests with some conifers as a result of the initiation of warming after the last glacial period.

During the middle Holocene (ca. 8000 to ca. 6000 cal BP), a marked increase in T-C-C in combination with the continued dominance of *Quercus* indicates that *Quercus*-dominated deciduous broadleaved forests still occupied the neighboring hills and mountainous area. However, pollen grains derived from conifers (mainly pine) and cold-tolerant *Betula* growing under cool and dry conditions showed slight decreases in relative abundance, indicating warm and wet conditions in the area. Moreover, wet-tolerant Cyperaceae (sedges) covered the lowland area owing to optimal ecological conditions (i.e., warm and wet) during the climate changes that started around 8000 cal BP. Large increases in the palynological concentration also indicate the expansion of vegetation cover caused by the hypsithermal conditions.

The palynofloras recovered here from this early to middle Holocene period probably reflect the warmest climatic conditions recorded in the palynological record. The pollen assemblages are comparable to those found in the west-central part of the Korean Peninsula (e.g., Yoon, 1997; Yi et al., 2004, 2008; Jang et al., 2006), which were interpreted as reflecting middle Holocene hypsithermal conditions. This interpretation is also supported by palynological evidence from eastern China (e.g., Liu et al., 1992; Chen et al., 2000). Palynofloral data from both Korea and China indicate conditions that were wetter and warmer than present conditions in most areas of central Korea. These patterns suggest that climatic conditions in the middle Holocene were much better for plant growth than today, and the wetter conditions in central Korea reflect the enhanced influence of Pacific summer monsoons during the middle Holocene.

From ca. 6000 to ca. 4500 cal BP, the former *Quercus*-dominated deciduous broadleaved forest was replaced by a mixed conifer–deciduous broadleaved forest, indicating a shift to cool temperate climatic conditions. The climate changes accelerated the expansion of the mixed forest, which mainly consisted of *Pinus* and *Quercus* associated with some accessory cool temperate trees, including *Carpinus*, *Ulmus/Zelkova* (elm/zelkova), and *Betula* on the hills and in the mountainous area. However, water-tolerant *Alnus* (alder) trees that were adapted to local environments grew along streambanks or swamp edges.

5.2. Salt marsh, phytoplanktonic algae, and their implications for the depositional environment

The distinct species zonation of a salt marsh depends mainly on the salinity gradient, and the spatial distribution is also influenced by species' salt tolerance and interspecific competition (Crain et al., 2004). In general, terrestrially derived salt marshes are influenced

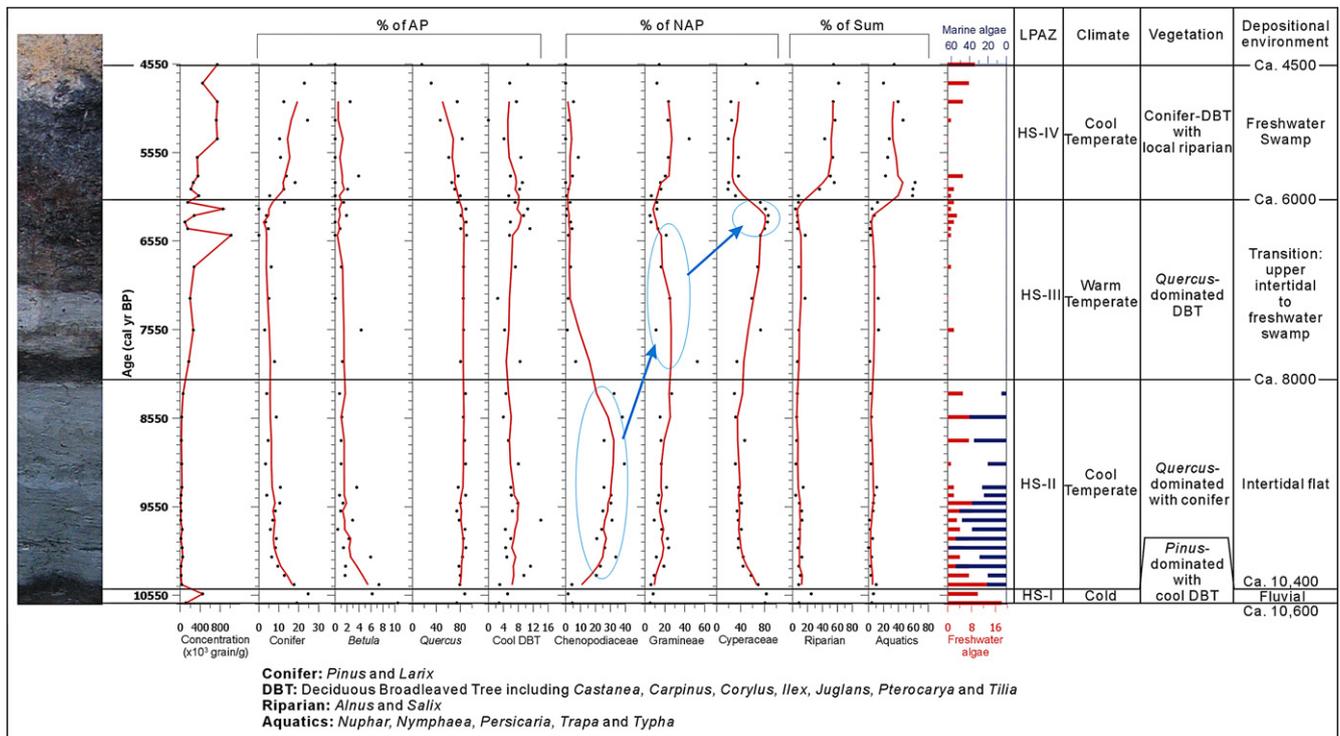


Fig. 4. Schematic diagram of selected pollen taxa showing the pollen zones with vegetation dynamic responses to climatic and depositional environmental changes during the early to middle Holocene. Three-point moving averages (red line) are shown for each reconstructed variable. Each arboreal pollen species is percentage of the arboreal pollen sum, excluding extreme dominant taxa, *Alnus* and *Taxaceae-Cephalotaxaceae-Cupressaceae*. Elongate circles and arrows show the directional alteration process of salt marshes correlating with general lithologic succession changing from light-green mud to gray mud to peat, in ascending order. AP = arboreal pollen; NAP = non-arboreal pollen.



Fig. 5. Modern salt marsh community growing on a tidal flat in Suncheon Bay, Korea (Photo by Yi, August 2008), with *Suaeda japonica* (Chenopodiaceae, red) and *Phragmites australis* (Gramineae, green). Ch and Gr, microscopic photos of Chenopodiaceae and Gramineae pollen, respectively.

by environmental factors controlled directly or indirectly by salinity and sea-level changes. In turn, the pollen succession in a salt marsh can be used to reconstruct former coastal environments (e.g., Fletcher et al., 1993; Ramcharan, 2004; González and Dupont, 2009). Moreover, pollen concentration reflects the distance from the source of pollen production, the density of parent plants, and the depositional environment, although the concentration of recovered pollen also depends on sediment grain size containing pollen grains (Tyson, 1995).

A lower succession with zone HS-II is characterized by the predominance of halophytic derived Chenopodiaceae together with marine dinoflagellates and freshwater algae (Fig. 4). Today, most Chenopodiaceae, including *Suaeda glauca*, *Suaeda japonica*, *Salicornia herbacea*, *Atriplex subcordata*, and *Salsola komarovi* (Choo and Song, 2000), grow in coastal wetlands distributed along the western and southern coasts of the Korean Peninsula (Fig. 5). In addition, the palynological concentration in zone HS-II showed the lowest abundance throughout the palynological spectrum, which can be explained by an unsuitable environment for palynological deposition owing to coastal turbulence. In contrast, higher percentages of *Pinus* pollen were found among the lower three zones. These findings agree with those of Rochon and de Vernal (1994) who reported that pollen concentrations tend to decrease in abundance toward the sea whereas that of *Pinus* increases seaward. Chenopodiaceous halophytic plants cannot survive long periods of submersion in seawater (Shim et al., 2002). A low diversity and abundance of dinoflagellates also can reflect unstable, low-saline, neritic conditions rather than oceanic conditions. The palynofloral assemblages in the Hwangsan Trench suggest that the depositional environment in the Pyeongtaek wetland was an intertidal zone during the early Holocene (ca. 10 400 to ca. 8000 cal BP), comparable to the transgression stage in the Yellow Sea (Chang and Choi, 2001; Lim and Park, 2003; Lee et al., 2008).

During the middle Holocene (ca. 8000 to ca. 6000 cal BP; zone HS-III), members of the Chenopodiaceae markedly decreased and were replaced by meso- to hyperhaline-derived members of the Gramineae and by mesohaline-derived members of the

Cyperaceae. The Gramineae began to decline in frequency toward the top of this zone, whereas the Cyperaceae increased. Generally, members of the Cyperaceae are salt-sensitive species that grow only in mesohaline swamps (Crain et al., 2004). The gradual decrease in *Pinus* and increase in palynological concentration toward the top of the zone may also reflect changes in the depositional environment with soils of reduced salinity. Moreover, marine dinoflagellates disappeared at the lower boundary of this zone, but freshwater algae were still present. The palynological spectrum coincides with the lithologic characteristics of light-gray mud changing to peat. Together, these findings suggest that the depositional environments underwent a transition from upper intertidal to freshwater swamp from ca. 8000 to ca. 6000 cal BP (Fig. 4).

In zone HS-IV (ca. 6000 to ca. 4500 cal BP), the predominance of aquatic genera, such as *Typha*, *Persicaria*, *Nuphar*, and *Nyphaea*, associated with freshwater algae indicate that the Hwangsan Trench site had completely changed to a freshwater swamp. In addition, the wet soil conditions could help riparian genera, such as *Alnus* and *Salix*, flourish along swamp edges or streambanks. Autochthonous plants, such as these aquatic and riparian genera, that lived and died within the swamp provided for the deposition of plentiful organic material, resulting in the formation of a peat layer.

6. Conclusions

In this study, past changes in vegetation, climate, and depositional environment were deduced from palynological records of the Hwangsan Trench in the Pyeongtaek wetland, with chronological control provided by calibrated radiocarbon dates. During the early Holocene (ca. 10 400–8000 cal BP), *Quercus*-dominated, temperate, deciduous broadleaved forest together with conifers and cool-tolerant birch flourished on the adjacent hills and mountainous areas under the cool and dry conditions at the beginning of post-glacial warming. The depositional environment was an intertidal flat, as indicated by the halophytic salt marsh containing

Chenopodiaceae and marine dinoflagellates. The climate became warm and wet between ca. 8000 and ca. 6000 cal BP. Areas continued to be occupied by *Quercus*-dominated deciduous broadleaved forest but with decreased conifers and cool-tolerant birch. The disappearance of marine dinoflagellates and an abundance of meso- to hypersaline salt marshes containing Gramineae accompanied with a later increase in mesosaline Cyperaceae indicate a transition from intertidal to freshwater swamp. From ca. 6000 to ca. 4500 cal BP, previous *Quercus*-dominated deciduous broadleaved forests were replaced by mixed conifer–deciduous broadleaved forests as the climate changed to cool temperate conditions. At this time, water-tolerant *Alnus* trees adapted to local environments grew along streambanks and swamp edges. Aquatic genera, such as *Persicaria*, *Nuphar*, and *Nyphaea*, associated with the presence of freshwater algae indicate that the study area had changed completely to a freshwater swamp. The directional sequence in relative abundance of taxa from an initial maximum pollen percentage of Chenopodiaceae followed by those of Gramineae, Cyperaceae, and aquatics, suggests a gradational pattern indicative of marked environmental clines typical of intertidal habitats. The directional alteration process of salt marshes is also comparable to the general lithologic sequence changing from greenish light-gray mud to light-gray mud to peat, in ascending order.

Acknowledgements

This research (GP2009-005) was supported by the Basic Research Project of the KIGAM funded by the Ministry of Knowledge Economy of Korea. Two reviewers are sincerely thanked for their constructive comments.

References

- Byrne, R., Ingram, B.L., Starratt, S., Malamud-Roam, F., Collins, J.N., Conrad, M.E., 2001. Carbon-isotope, diatom, and pollen evidence for late Holocene salinity change in a brackish marsh in the San Francisco estuary. *Quaternary Research* 55, 66–76.
- Chang, J.H., Choi, J.Y., 2001. Tidal-flat sequence controlled by Holocene sea-level rise in Gomso Bay, west coast of Korea. *Estuarine, Coastal and Shelf Science* 52, 391–399.
- Chang, N.K., Rim, Y.D., 1979. *Morphological Studies on the Pollen of Flowering Plants in Korea*. Seoul National University Press, Seoul, 62 pp.
- Chen, Z., Song, B., Wang, Z., Cai, Y., 2000. Late quaternary evolution of the sub-aqueous Yangtze Delta, China: sedimentation, stratigraphy, palynology, and deformation. *Marine Geology* 162, 423–441.
- Choo, Y.-S., Song, S.-D., 2000. Ecophysiological characteristics of Chenopodiaceae plants: an approach through inorganic and organic solutes. *Korean Journal of Ecology* 23, 397–406 (in Korean with English abstract).
- Crain, C.M., Silliman, B.R., Bertness, S.L., Bertness, M.D., 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. *Ecology* 85, 2539–2549.
- Danzeglocke, U., Jöris, O., Weninger, B., 2009. CalPal-2007. online. <http://www.calpal-online.de/>.
- Fletcher, C.H., van Pelt, J.E., Brush, G.S., Sherman, J., 1993. Tidal wetland record of Holocene sea-level movements and climate history. *Palaeogeography, Palaeoclimatology, Palaeoecology* 102, 177–213.
- van Geel, B., Bohncke, S.J.P., Dee, H., 1981. A palaeoecological study of an upper late glacial and Holocene sequence from “De Borchert”, The Netherlands. *Review of Palaeobotany and Palynology* 31, 367–448.
- van Geel, B., Hallewas, D.P., Pals, J.P., 1982. A late Holocene deposit the Westfriese Zeedijk near Enkhuizen (Prov. Of Noord-Holland, The Netherlands): palaeoecological and archaeological aspects. *Review of Palaeobotany and Palynology* 38, 269–335.
- van Geel, B., Coope, G.R., van der Hammen, T., 1989. Palaeoecological and stratigraphy of the lateglacial type section at Usselo (The Netherlands). *Review of Palaeobotany and Palynology* 60, 25–129.
- González, C., Dupont, L.M., 2009. Tropical salt marsh succession as sea-level indicator during heinrich events. *Quaternary Science Reviews* 28, 939–946.
- Grimm, E., 1987. CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computer Geoscience* 13, 1335.
- Grimm, E., 1991. TILIAGRAPH v1.25 (Computer Software). Illinois State Museum, Research and Collections Center, Springfield, IL, USA.
- Grimm, E., 1993. TILIA v2.0 (Computer Software). Illinois State Museum, Research and Collections Center, Springfield, IL, USA.
- Jang, B.O., Yang, D.Y., Kim, J.Y., Choi, K.R., 2006. Postglacial vegetation history of the central western region of the Korean peninsula. *Journal of Ecology and Field Biology* 29, 573–580 (in Korean with English abstract).
- KIGAM, 2005. Study on Earth's Environmental Change Using Quaternary Sedimentary Records: Phase I. Report of Korea Institute of Geoscience and Mineral Resources, OAA2004002–2005(2), 267 pp. (in Korean with English abstract).
- Lee, J.H., 2003. A study of plant fossils from peat sediments of the Pyeongtaek area. M.Sc. thesis of Chungbuk National University, 44 p. (unpublished).
- Lee, Y.G., Choi, J.M., Oertel, G.F., 2008. Postglacial sea-level change of the Korean southern sea shelf. *Journal of Coastal Research* 24, 118–132.
- Lim, D.I., Park, Y.A., 2003. Late quaternary stratigraphy and evolution of a Korean tidal flat, Haenam Bay, southeastern Yellow Sea, Korea. *Marine Geology* 193, 177–194.
- Liu, K.B., Sun, S., Jiang, X., 1992. Environmental change in the Yangtze River delta since 12,000 years B.P. *Quaternary Research* 38, 32–45.
- Malamud-Roam, F., Ingram, B.L., 2004. Late Holocene $\delta^{13}\text{C}$ and pollen records of paleosalinity from tidal marshes in the San Francisco Bay estuary, California. *Quaternary Research* 62, 134–145.
- Mitsch, W.J., Gosselink, J.G., 2000. *Wetlands*, third ed. John Wiley & Sons, New York, 920 pp.
- Moore, P.D., Webb, J.A., Collinson, M.E., 1991. *Pollen Analysis*, second ed. Blackwell Scientific Publications, Oxford, 216 pp.
- Mudie, P.J., Harland, R., 1996. Aquatic quaternary. In: Jansonius, J., McGregor, D.C. (Eds.), *Palynology: Principles and Applications*. American Association of Stratigraphic Palynologists Foundation, pp. 843–877.
- Ramcharan, E.K., 2004. Mid-to-Late Holocene sea level influence on coastal wetland development in Trinidad. *Quaternary International* 120, 145–151.
- Rochon, A., de Vernal, A., 1994. Palynomorph distribution in recent sediments from the Labrador Sea. *Canadian Journal of Earth Sciences* 31, 115–127.
- Ryu, E., Nahm, W.H., Yang, D.Y., Kim, J.Y., Lee, S.J., 2007. Late quaternary environmental changes from diatom record of the Pyeongtaek wetland in Korea. *Journal of Geological Society of Korea* 43, 167–181 (in Korean with English abstract).
- Shim, H.B., Seo, S.M., Choi, B.H., 2002. Floristic survey of salt marshes and dunes on Geyonggi Bay in Korea. *Korean Journal of Environmental Biology* 20, 25–34 (in Korean with English abstract).
- Stockmarr, J., 1972. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13, 615–621.
- Traverse, A., 1988. *Paleopalynology*. Unwin Hyman, Boston, 600 pp.
- Tyson, R.V., 1995. *Sedimentary Organic Matter*. Chapman & Hall, London, 615 pp.
- Weninger, B., Jöris, O., 2008. A ^{14}C age calibration curve for the last 60 ka: the Greenland-Hulu U/Th timescale and its impact on understanding the middle to upper paleolithic transition in Western Eurasia. *Journal of Human Evolution* 55, 772–781.
- Yi, S., Nam, S.-I., Chang, S.-W., Chang, J.H., 2004. Holocene environmental changes in the tidal sediments of the west coast of South Korea inferred from pollen records. *Journal of the Geological Society of Korea* 40, 213–225 (in Korean with English abstract).
- Yi, S., Kim, J.Y., Yang, D.Y., Oh, K.C., Hong, S.S., 2008. Mid- and Late Holocene palynofloral and environmental change of Korean central region. *Quaternary International* 176–177, 112–120.
- Yoon, S.O., 1997. The Holocene environmental changes and reconstruction of the palaeogeography at the Ilsan area with special reference to pollen analysis. *Journal of the Korean Geographical Society* 32, 15–30 (in Korean with English abstract).