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< Review >

Global Warming and Alpine Vegetation

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ABSTRACT: Reconstruction of the past vegetational changes of Korea in connection with climate changes enables to understand the impacts of past and future global warming on alpine vegetation. Despite the early appearance of the cold-tolerant vegetation since the Mesozoic Era, the occurrence of warmth-tolerant vegetation during the Oligocene and Miocene implies that most of alpine and subalpine vegetations have been confined to the alpine and subalpine belts of northern Korean Peninsula. The presence of cold-episodes during the Pleistocene, however, might have caused a general southward and downslope expansions of cold-tolerant alpine and subalpine vegetation. But the climatic warming trend during the Holocene or post-glacial period eventually has isolated cold-tolerant alpine and subalpine vegetation mainly in the northern Korea, but also on scattered high mountains in the southern Korea. The presence of numerous arctic-alpine and alpine plants on the alpine and subalpine belts is mainly due to their relative degree of sensitivity to high summer temperatures. Global warming would cause important changes in species composition and altitudinal distributional pattern. The altitudinal migration of temperate vegetation upward caused by climatic warming would eventually devastate alpine plants.

Key Words: Alpine vegetation, Cold-tolerant vegetation, Global warming, High summer temperature, Holocene, Pleistocene, Subalpine vegetation, Warmth-tolerant vegetation.

INTRODUCTION

Many people are concerned about the possible ecological effects that are associated with global climate change. The UN appointed board of 2,400 scientists from around the world has concluded that: 1) there have been global temperature increases over the past 100 years, 2) these increases can be attributed to anthropogenic sources, and 3) temperature increases over the next century are predicted to be up to 3.5℃.

There are positive and negative economic impacts concerning global warming. It has been predicted that some subarctic and boreal areas of the world could see an increase in their growing seasons and this would produce larger crop yields for these countries. It has also been speculated that increased carbon dioxide levels may allow plants to grow more rapidly. The negative side of this scenario is that other countries will be dealing with severe drought conditions or be inundated with water due to the rising sea levels.

Many works have been done on the impacts of climate change on vegetation (Krauchi 1992, Woodwell 1990, Woodward 1992, Billings and Peterson 1992, Enoch and Honour 1993, Winiger 1999). People, however, do not seem to concern about the future of plants at the subalpine and alpine belts in the temperate zones. The past is often regarded as a key to the future and the use of palaeo-environmental understanding is important to predict the effects of human-being on the biosphere (Huntley 1990, 1992, Adams and Woodward 1992, Socci 1993).

Present work aims to reconstruct the past vegetational changes of the Korean Peninsula in connection with climatic changes by the use of fossil plant data, and to understand the potential impact of climate changes on vegetation. with special references to the distribution of arctic-alpine and alpine plants of Korea, which are sensitive to global warming.

GLOBAL WARMING

According to the Ecologists' Statement to the President of USA in 1997, climate change driven by emissions of greenhouse gases is projected to occur at a very rapid rate, significantly faster, on a sustained global basis, than rates of climatic change during the past 10,000 years. Rapid climate change coupled with pollution, habitat fragmentation and habitat loss may lead to the decline and disappearance of many plant and animal communities that might otherwise survive a future climate that is relatively stable but warmer.

Global mean temperature could increase by as much as 1-3.5℃ over the next 100 years. Rapid climate change is more dangerous to plant and animal communities than gradual climate change even if the total amount of change that eventually occurs is exactly the same. In fact, many natural areas now can be considered as 'islands' in a sea of developed land. This is especially true for the arctic-alpine and alpine plants on the mountain tops of temperate zone. Overall, climate change, in combination with existing anthropogenic habitat disruption and loss, could lead to steep declines in worldwide biodiversity.

Over many centuries, plants and animals have evolved natural resistances to changes brought on by the environment; however, since global warming threatens to bring about rapid environmental changes in the span of a few decades, many species will be faced with shifting habitats, damages to migration patterns, loss of food sources, and other problems that could devastate their populations. They also face the incredible challenge of adapting to these massive changes in a short amount of time. The problem with this is that species will not be able to develop natural resistances in such a short time, since it takes millions of years to build up these resistances. Importantly, these changes could also lead to affect humans in negative ways.

Climate change and past vegetation

To understand how rapid climate changes affect the ability of species to survive, it is important to look at how global warming affects particular species, such as cold-tolerant plant species. In the Arctic and alpine areas, as the cold temperatures rise, many species which both live and migrate to this system face extreme complications. Plant species will fair poorly because of global warming. Currently, the effects of climate change on plant species can be seen on glacial mountain tops, where meadows are being replaced by sagebrush.

By analyzing climatic proxy data of Korea, such as fossil pollen (Kong 1995, 1996, 1997), ocean sediments (Park 1992, 1995), tree rings (Park 1994, 1996) and historical data (Kim 1987, 1990), scientists can extend our understanding far beyond the 100-year instrumental record provided by thermometers. The instrumental temperature record indicates that the Earth has warmed by 0.5℃ from 1860 to the present. The thermal increase of Korea is, however, marked about 1.0℃ for the last 100 years.

Present work employed mainly fossil pollen data from 40 sites for the conifers and 75 sites for the dicotyledons (Kong 1995, 1996, 1997) to understand the impact of climate changes on alpine vegetation within the time-frame from the Permian Period of the Palaeozoic Era to the present day.

Concerning the Palaeozoic Era (*c.* 286 to 248 million years B.P.), the oldest plant fossil in Korea dates back to the Carboniferous Period, and the oldest conifers to the Permian Period of Palaeozoic Era. During the Mesozoic Era (*c.* 248 to 65 million years B.P.), the only conifer which successfully survived since the Cretaceous Period is *Pinus* which still thrives (Table 1).

In the case of dicotyledons the oldest flora dates back to the Cretaceous Period of the Mesozoic Era, and seven genera *i.e.*, *Viburnum*, *Salix*, *Cinnamomum*, *Ilex*, *Grewia*, *Aralia* and *Lindera* still grow naturally in the wild (Table 2). The presence of thermophilous (warmth-tolerant) plants such as *Cinnamomum* and *Ilex* indicates that the climate of some places during this period was relatively warm.

In the case of Cenozoic Era (since *c.* 65 million years B.P. to present), no floral fossil informations are available for the Palaeocene and Eocene Periods in Korea. Out of the twelve dicotyledons of the Oligocene Period (*c.* 38 to 24.6 million years B.P.) reported from North Korea, eleven genera still do survive in Korea. Miocene dicotyledons which are discovered both in South and North Korea reach up to seventy-two genera, out of which fifty-six are still growing.

The first appearance of many of the present-day floristic genera indeed dates back to the Oligocene. The presence of warmth-tolerant genera such as *Myrica*, *Ficus* and *Hedera* in the Oligocene at up to 37°30′N, which is four degrees north of their present distributional limits implies that the climate of the Oligocene was warmer than that of today. The extinction of many conifers, such as *Sciadopitys*, Taxodiaceae, *Metasequoia* and *Cryptomeria* Miocene Period (*c.* 24.6 to 5.1 million years B.P.) may be due to the climatic deteriorations during the late Pleistocene Period. However, the cryophilous (cold-tolerant) conifers, *e.g.* *Pinus*, *Juniperus*, *Abies*, *Picea*, Cupressaceae, *Larix* and *Taxus* continued to exist from the Miocene to the late Pleistocene and became major vegetational elements in the mountains of Korea, especially in the subalpine and alpine belts.

The occurrence of similar thermophilous floristic element at 42°N, for example *Cinnamomum*, *Cyclobalanopsis* and *Ilex* which is at up to six degree north of present range during the middle Miocene suggests a maximum northward expansion of warmth-tolerant evergreen broad-leaved vegetation for the recent Korean vegetation history. Consequently, the range of cold-tolerant plants might have retreated and been confined toward north and mountain tops.

Table 1. Fossil conifers of Korea

Genera \ Era	Pal.	Mesozoic			Cenozoic							Korean Name(속명)
	Per.	Tri.	Jur.	Cre.	Pac.	Eoc.	Oli.	Mio.	Ple.	Hol.	Pre.	
*Walchia**	===											왈치아
*Sequoia**				===								세콰이아
Pinus(diploxylon)				===				===	===	===	===	소나무(2엽)
*Metasequoia**.								===	===			메타세콰이아
Picea								===	===	===	===	가문비나무
Abies								===	===	===	===	전나무
Tsuga								===	===		===	솔송나무
Juniperus								===	===	===	===	노간주나무
Larix								===	===		===	이깔나무
Cephalotaxus								===			===	개비자나무
Taxus								===	===		===	주목
Thuja									===		===	찝방나무
Pinus(haploxylon)									===		===	소나무(5엽)

* Asterisk indicates extinct or introduced genera   Sources: Kong (1995, 1997)
Abbreviations : Pal. = Palaeozoic, Per. = Permian, Tri. = Triassic, Jur. = Jurassic, Cre. = Cretaceous, Eoc. = Eocene, Oli. = Oligocene, Mio. = Miocene, Ple. = Pleistocene, Pre. = Present

Table 2. Fossil dicotyledons of Korea

Genera \ Era	Pal.	Mesozoic			Cenozoic							Korean Name (속명)
	Per.	Tri.	Jur.	Cre.	Pac.	Eoc.	Oli.	Mio.	Ple.	Hol.	Pre.	
Salix				===				===	===	===	===	버드나무
Cinnamomum				===				===	===		===	녹나무
Ilex				===			===	===	===	===	===	감탕나무
Juglans							===	===	===	===	===	호도나무
Acer								===	===	===	===	단풍나무
Carpinus								===	===	===	===	서나무
Quercus								===	===	===	===	참나무
Betula								===	===	===	===	자작나무
Alnus								===	===	===	===	오리나무
Tilia								===	===	===	===	피나무
Rhododendron								===			===	철쭉나무
Fraxinus								===	===	===	===	물푸레나무
Sorbus								===	===		===	마가목
Magnolia								===	===		===	목련
Celtis									===	===	===	팽나무
Benzoin									===		===	털생강나무
Buxus									===		===	회양목
Daphne									===		===	서향나무
Acanthopanax									===		===	오갈피나무

Sources: Kong (1996, 1997)

In the Pleistocene (*c.* 2 to 0.1 million years B.P.), the admixture of cold-tolerant evergreen coniferous plants *e.g. Taxus, Abies* and *Thuja* and deciduous broad-leaved plants indicates a probable temperate climate for much of the middle Pleistocene of the Korean Peninsula. The presence of cold-episodes during the upper Pleistocene might have caused a general expansion of deciduous broad-leaved plants and cryophilous evergreen coniferous plants as well as the southward expansion of cold-tolerant arctic-alpine and alpine floras in the Korean Peninsula. From seventeen sites of Korea, fifty-three genera of dicotyledons appeared during the Pleistocene, but only three genera, *i.e. Engelhardtia, Raphidephis* and *Sapium* appears to be extinct at present, which in turn imply that most of Korean plants have succeeded to find places or habitats to survive.

The disappearances of some cryophilous genera, such as *Pinus* (haploxylon), *Picea, Abies, Larix* and so on from the Holocene Period (since 0.1 million years B.P.) marks the continued climatic amelioration since then, along with minor climatic fluctuation during the Holocene. As the temperature ameliorates in the late Holocene, warmth-tolerant *Pinus* (diploxylon) had gradually increased in numbers and became a dominant vegetation in the lowland and montane areas since 2,000 years B.P. Nearly all dicotyledons which were discovered from fourteen Holocene deposits of southern Korea have successfully survived to the present.

Overall, despite the early appearance of cold-tolerant conifers, *i.e.*, *Pinus* since the Mesozoic Era, the presence of thermophilous genera such as *Myrica*, *Ficus* and *Hedera* in the Oligocene at up to four degrees north of their present distributional limits implies that during the Oligocene most of cryophilous plants have been confined to the alpine and subalpine belts of northern parts of the Korean Peninsula. The occurrence of thermophilous plants, for example *Cinnamomum*, *Cyclobalanopsis* and *Ilex* at up to six degrees north of present range during the middle Miocene suggests a maximum northward and up-slope retreats of alpine and subalpine vegetational belts for the Korean vegetational and environmental history.

The admixture of evergreen coniferous plants *e.g.* *Taxus*, *Abies* and *Thuja* and deciduous broad-leaved plants indicates a probable temperate climate for much of the middle Pleistocene of Korea. The appearance of deciduous broad-leaved plants and cryophilous evergreen coniferous trees, such as *Taxus*, *Abies*, *Picea*, *Tsuga*, *Pinus* and *Thuja* within the Korean Peninsula indicates the existence of cold episodes during the upper Pleistocene. The presence of cold-episodes during the upper Pleistocene might have caused a general southward expansion of cold-tolerant alpine and subalpine vegetation in Korea.

The disappearance of some cryophilous genera, such as *Pinus* (haploxylon), *Picea*, *Abies*, *Larix* and so on, from 10,000 years B.P. marks the continued climatic amelioration since then, along with minor climatic fluctuations during the Holocene. This climatic warming trend eventually has isolated cryophilous alpine and sub-alpine plants mainly in the northern Korea but also on scattered high mountains in the southern Korea.

The disjunctive distribution of many alpine and subalpine vegetation which are likely to have been formed during the post-glacial warming phase (Kong 1998a) suggests a former continuous distribution of these both locally and on a broader scale, and their range expansion downslopes and southwards during the Pleiostocene glacial phases, but the subsequent break-down of a former continuous range into fragments as the climate ameliorated during the post-glacial warming phase.

Climate change and present vegetation

Current phyto-geographical data on the distribution of cold-tolerant plants are collected and collated from many high mountains of Korea to detect the short-term environmental changes. The presences of numerous cryophilous plants on the alpine and subalpine belts of the Korean Peninsula, are mainly due to their relative degree of sensitivity to high summer temperatures. The continued survival of alpine species in Korea is in danger if global warming associated with the greenhouse effect takes place.

Out of the eight biogeographical zones in the Korean Peninsula (Kong 1989, 1990) which have been established based upon the distribution of evergreen plants and consist of northern alpine region, alpine and subalpine belts occur mainly in the northern alpine region and north-south subalpine region, but disjunctively in the areas of the southern insular region and west-south-east and associated inland region.

Alpine belt is mainly found in the northern alpine region of Korea and includes eleven sites, such as Mts. Moosan, Paikdoo, Kwanmo, Mantap, Keeju, Kapsan, Chilbo, Hoochi, Ro, Keumpae and Danchon. Alpine belt contains twenty-five cold-tolerant plant species, such as *Taxus cuspidata* var. *latifolia*, *Juniperus sibirica*, *J. utilis*, *Picea intercedens*, *P. tonaiensis*, *Pinus pumila*, *Andromeda polifolia*, *A. polifolia* form. *acerosa*, *Chamaedaphne calyculata*, *Dryas octopetala* var. *asiatica*, *Empetrum nigrum* var. *japonicum*, *Ledum palustre* subsp. *decumbens*, *L. palustre* var. *latifolium*, *L. palustre* var. *maximum*, *L. palustre* var. *minus*, *L. palustre* var. *procumbens*, *L. palustre* var. *yesoense*, *Linnaea borealis*, *Oxycoccus microcarpus*, *O. quadripetalus*, *Phyllodoce caerulea*, *Rhododendron aureum*, *R. fauriae* form. *rufescens*, *R. parvifolium* and *Vaccinium vitis-idaea* var. *genuinum*.

Eighteen arctic-alpine and alpine evergreen broad-leaved plants which do occur both in the Arctic and alpine belts of the mid-latitude, and four circumpolar evergreen coniferous plants and endemic species are noticed in the alpine belt. Four distinctive altitudinal range groups can be noticed in the alpine belt and include those: 1) from 450 to 550m which are occupied by evergreen coniferous plant *Juniperus utilis*; 2) from 800 to 1,500m by circumpolar evergreen broad-leaved plants *Rhododendron fauriae* form. *rufescens* and *R. parvifolium*; 3) from 2,000 to 2,000m by northern evergreen coniferous plants *P. pumila* and *Juniperus sibirica*; 4) from 1,500 to 2,540m by circumpolar evergreen broad-leaved plants such as *Ledum* spp., *Phyllodoce caerulea* and *Rhododendron aureum*.

Subalpine zone, however, occurs from northern to southern subalpine Korea and consists of twenty-one sites; Mts. Zung, Songjin, Chayoo, Seungjuk, Pirae, Peenanduk, Nangrim, Myohyang, Sasoo, Haram, Chuae, Kumkang, Sorak, Myungji, Odae, Kaebang, Taeji, Chiak, Daesung, Taebaik and Dukyoo. Though Mts. Chiri and Halla are excluded in the alpine and subalpine belts, these two sites also contain numerous arctic-alpine and alpine floristic elements. Subalpine belt is composed of twenty-eight cryophilous species, including *Abies nephrolepis, Picea jezoensis, Pinus koraiensis, Taxus cuspidata, Thuja koraiensis, Buxus koreana, Vaccinium vitis-idaea* var. *minus* and so on.

Subalpine belt consists of fifteen evergreen coniferous plants, ten evergreen broad-leaved plants and three evergreen bamboos, where trees and shrubs with small leaves are common. Out of the seven altitudinal ranges in the subalpine belt four groups are composed of cold-tolerant plants, 1) northern evergreen coniferous plants *Pinus koraiensis* and *Thuja koraiensis* from 300 to 2,300m, 2) *Taxus cuspidata, Abies nephrolepis* and *Picea jezoensis* from 500 to 1,900m, 3) northern evergreen coniferous plants *Pinus pumila* and *Juniperus chinensis* var. *sargentii* from 700 to 2,300m, and 4) circumpolar evergreen broad-leaved plants *Rhododendron fauriae* form. *rufescens, R. aureum* and *Vaccinium vitis-idaea* var. *minus* from 800 to 2,300m.

Several cryophilous trees such as *Abies koreana, Picea jezoensis, Taxus cuspidata* and *Juniperus chinensis* var. *sargentii* are also found in Mt. Chiri, and *Abies koreana, A. holophylla, Juniperus chinensis* var. *sargentii, Taxus cuspidata, Diapensia lapponica* subsp. *obovata, Empetrum nigrum* var. *japonicum, Rhododendron dauricum, R. fauriae* var. *roseum, R. fauriae* form. *rufescens, Vaccinium bracteatum* and *V. uliginosum* are reported from Mt. Halla. In the case of Mt. Halla circumpolar evergreen broad-leaved plants *Diapensia lapponica* subsp. *obovata, Empetrum nigrum* var. *japonicum, Vaccinium uliginosum,* and the northern evergreen coniferous plants *Abies holophylla, Juniperus chinensis* var. *sargentii* and *Taxus cuspidata* are found from 1,800 to 1,950m and endemic *Abies koreana* grow from 1,300 to 1,950m (Kong 1998b). The arctic-alpine and subalpine plants, which consist of circumpolar evergreen broad-leaved plants and northern evergreen coniferous plants, are confined to their range on the northern alpine and north-south subalpine belts as well as to few high mountains in the south.

Within the Korean Peninsula, seven major distributional patterns can be found from the arctic-alpine and alpine plants, *viz.*, 1) species which are present throughout the peninsula, 2) species present from the north to the midlands, 3) species occurring both in the north and in Cheju Island, but not in between, 4) endemic species which are present in the south and Cheju Island, 5) species which are restricted solely to the north, 6) species which are restricted to the midlands, and 7) species which is restricted to the Cheju Island.

In respect of the vertical distributional range relating to the means of the lower limits for the arctic-alpine and alpine plants for which data are available, four distinct divisions may be delineated, *viz.*, 1) the altitudes of *c.* 500m to 1,000m a.s.l. which are dominated mainly by coniferous trees, 2) at *c.* 1,000m a.s.l. in which endemic coniferous trees grow, 3) from *c.* 1,000m to 1,500m a.s.l. in which coniferous and broad-leaved trees mixed and 4) from *c.* 1,500m to 1,800m a.s.l. and above, where communities are dominated by the evergreen broad-leaved trees.

The presence of arctic-alpine and alpine evergreen broad-leaved trees at *c.* 1,500m to 1,800m a.s.l. or above, in which low summer temperatures and very cold winter temperatures prevail, is no doubt due to their physiognomic and ecophysiological adaptations against cold environments. Below the alpine belts, or in the south, where high summer temperatures prevail, these adaptations are disadvantageous to the survival of arctic-alpine and alpine evergreen broad-leaved trees. The presence of numerous arctic-alpine and alpine plants on the alpine and subalpine belts, mainly in the north, but also in the midlands, the south and Cheju Island is mainly due to their relative degree of sensitivity to high summer temperatures.

The present occurrence of several arctic-alpine species in the alpine and subalpine belts of Korea which is the world's southernmost limit of their distribution, and of another species at the southernmost limit of their range in East Asia further indicates that climatic warming in the Korean Peninsula may be threatening the survival of those plants in the future (Kong 1999).

CONCLUSION

Climatic and biological systems are intertwined in the processes leading to impacts and feedbacks and so it has emerged that scientists in different fields, such as geographers and biologists must collaborate in research programmes. To understand better the processes of global warming and the ecosystem changes and impacts, this work concentrates on the impacts of global warming on the distribution of arctic-alpine and alpine plants of the Korean Peninsula.

The relationships between thermal warming and the distribution of cold-tolerant plants is not a single question and requires a wide range of spatial and temporal informations as well as functional ones. Palaeo-phytogeographic data provide convincing evidences that climate warming have retreated or even expelled the cryophilous plants from Korea in the past.

Global warming would cause important changes in species composition and altitudinal distributional pattern. Temperate deciduous trees would invade into current subalpine belt. Various evergreen and deciduous coniferous trees would be outcompeted from subalpine belt and migrate into today's alpine belt. These altitudinal migration upward would eventually devastate alpine plants. Rates of species spread in response to Holocene climate changes normally range from 50~200m/yr for most of the woody species in Europe and North America (Davis 1976, Huntley and Birks 1983, Huntley 1988). If current anthropogenic global warming trend maintains, the continued survival of arctic-alpine and alpine plants in the Korean Peninsula which are now confined mainly to the mountain tops at the world's or East Asia's southernmost limits of distribution will be in danger.

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