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*Review*

# Forest decline of the world: A linkage with air pollution and global warming

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**Various forest declines and forest health conditions have been described for forest ecosystems throughout the world. The connection to global warming and air pollution is clear in some area, but not in others. In this study, some evidences that support or contradict air pollution and global warming being causal factors in reported cases of decline in Eastern North America, Central Europe and Republic of Korea. Many studies suggested that forest decline phenomenon seems to be strongly associated to air pollution and global warming.**

**Key words:** Abiotic stress, air pollution, forest decline, tree physiology.

## INTRODUCTION

Forest decline has been observed in the plantation forests of Central Europe, Eastern North America and the Pacific region in recent decades. Forest decline first came to public attention when the dominant silvicultural tree of Germany showed damage on a large geographic scale. Damaged Norway spruce (*Picea abies* L. Karts) displayed decline symptom which could not be explained by known pathogen or other biotic factors (Manion, 1991).

Many researchers thought that forest decline had been initiated by abiotic factors-not biotic agents. However, forest decline is needed for problems associated with an array of interacting biotic and abiotic factors. Forest decline may have been attributed to insects, pathogens, disturbances in forest, climate factors, competition, acid rain, nutrient deficiency, elevated $CO_2$, or air pollution (Houston, 1981; Smith, 1992).

The causes of this widespread phenomenon are unknown. Furthermore, the concept of the forest is a complex dynamic structure of tree groups and associated vegetation. Numerous observations and studies have implicated air pollution, such as ozone and acid rain, as one of the possible causes. This scientific report includes: phenolmenon and explanation of the forest decline in various area. Forest decline issue is quite a deep topic. This article will permit the reader to have general idea about forest decline.

## DEFINITION OF FOREST DECLINE

Definition of forest decline is not founded on a universal set of standard. Forests are complex dynamic communities of living and dead trees among themselves with an array of microbes, pests, environmental and other factors which continuously shape the community over time. Several definitions have been developed.

Forest decline concept cannot be properly interpreted with a single agent. Decline is characterized by the presence of symptoms such as reduced growth, shortened internodes, root necrosis, premature fall coloring, yellowing and loss of foliage, dieback of twigs and branches generally beginning in the upper crown, sprouting from adventitious buds, increased prevalence and pathogenicity of root decay, simplification of structural diversity, biotic impoverishment, reduced species diversity and reduced forest stands dynamics (Manion, 1991).

Manion and Lachance (1992) described forest decline as an episodic event characterized by premature, progressive loss of tree and stand vigor and health over a given period without obvious evidence of a single clearly identifiable casual factor such as physical disturbance or attack by an aggressive disease or insect.

### Forest decline in Central Europe

An unexplained foliar disease on European silver fir at high elevation had been noted (Lovett and Kinsman, 1990). Damaged Norway spruce (*Picea abies* L. Karts) died in abnormal numbers in this area (Keller and Hasler, 1987). These phenomena were initially considered

to be due to drought, insect damage, competitive status, climate and weather pattern (Johnson, 1983).

Not long ago, it had been suggested that air pollution might play an important role in the forest decline in Europe. This is supported by the fact that damage has been noted particularly in spruce forests at high elevations, since it is well known that air at high altitude is enriched with ozone (Keller and Hasler, 1987).

### Forest decline in Eastern North America

Recent observations of Norway spruce (*Picea abies* L. Karts) in the high elevation forests of New York and New England have indicated substantial and widespread mortality under these particular circumstances (Peart et al., 1992). Sugar maple, Balsam fir, American beech and red oak stands showed declines during 1950s and 1960s (McLaughlin, 1985; Millers et al., 1989).

Extreme wind events, spruce beetle or spruce budworm have been suggested as causes of this forest stands decline. However, one out of all of them could not explain why forest decline is occurring in this area. Air pollution stress, which can result in nutrient imbalance and alteration of cold resistance, may contribute to their decline (Brown et al., 1987).

### Forest decline in Republic of Korea

North-east Asian forest does not show widespread forest decline. However, reduced growth rate and leaf chlorosis were reported in industrialized areas (Kim, 1992). Some *Abies hollophylla* and *Qercus accutissima* stands which were located near industrialized areas in the southern part of Korea at high elevation have died in recent decades (Kim et al., 1993).

The regional decline of Korean fir (*Abies koreana*) was recognized in 1980s. Unfortunately, with an increasing argument on the decline phenomenon of this species, there has been little consensus on the detail causes of the dieback. Many researchers reported this dieback is probably the results of complex interactions among multiple environmental factors caused by global warming (Drohan et al., 2002; Duchesne et al., 2005).

Even thought temperature and water relation seem to be of great significance in Korean fir dieback, little is known about the relationship between temperature and water relations. Increasing temperature and water use efficiency of Korean fir in Mt. Halla are strongly associated with photosynthesis during growing season (Woo et al., 2008). Generally, elevated temperatures increase rates of chemical and biochemical processes in plants and soils in a similar way if nutrients are available (D'Alessandro et al., 2006; Hamrick, 2004). However, this common fact seems to be a reverse in certain region where a particular plant such as Korean fir adopted to low temperature on high elevation in northern hemisphere for long time. Some experimental data indicate that elevated temperature reduces net photosynthesis (Leverenz et al., 1999).

## FOREST DECLINE AND GLOBAL WARMING

Elevated $CO_2$ concentration stimulated tree growth and developments (Callaway et al., 2001). Enriched $CO_2$ concentration increases photosynthesis, radial growth, leaf area, productivities and physiological capacities of plant and algea (Saxe et al., 1998; 2001). Therefore, increased temperature effects on individual plants processes have been extensively studied (Mynenl et al., 1997; Blaustein and Kiesecker, 2002; Medlyn et al., 2002; Cunningham and Read, 2003).

However, increased atmospheric temperature during this century due to the global warming is not always one of the positive factors in plant growth environments. Sugar maple (*Acer saccharum*) decline has been observed in northern Pensnsylvania since the early 1980s because declining stands often experience repeated drought stresses (Drohan et al., 2002). Reduced growth of Alaskan white spruce in the 20th century from temperature- induced drought stress (Barber et al., 2000). Single or combined effects of climatic extremes such as winter frost and summer drought, have been attributed as one of the causes of oak decline in Central Europe (Thomas et al., 2002).

Winter desiccation and altered water use efficiency (WUE) on the trees in high elevation are the unfavorable by-products of the global warming in high located mountain ecosystem (Cairns, 2001). *Abies lasiocarpa* in Glacial National Park, winter desiccation resulting in water stress on vegetation shows a strong correlation with elevation and injury increases with elevation and on more southwesterly facing hillslopes. Traditional, winter injury has commonly been considered to be the result of desiccation stress that develops during winter (Adams and Kolb, 2005).

In these totally different regions, dieback phenomenon has been shown single trees or groups of trees within stands, parts of stands and whole stands.

## SEVERAL MODELS TO EXPLAIN FOREST DECLINE

Various decline models were suggested. Houston (1981) expresses the model as a series of stress and response reaction. The central importance of organisms of secondary action in the central stressed trees was emphasized (Figure 1).

Healthy trees are affected by environmental stress; tree tissues altered by that stress are invaded at some point in time by unknown pathogen. The disease condition develops, tissues and trees decline and ultimately may die.

Manion and Lachance (1992) developed a three tiered

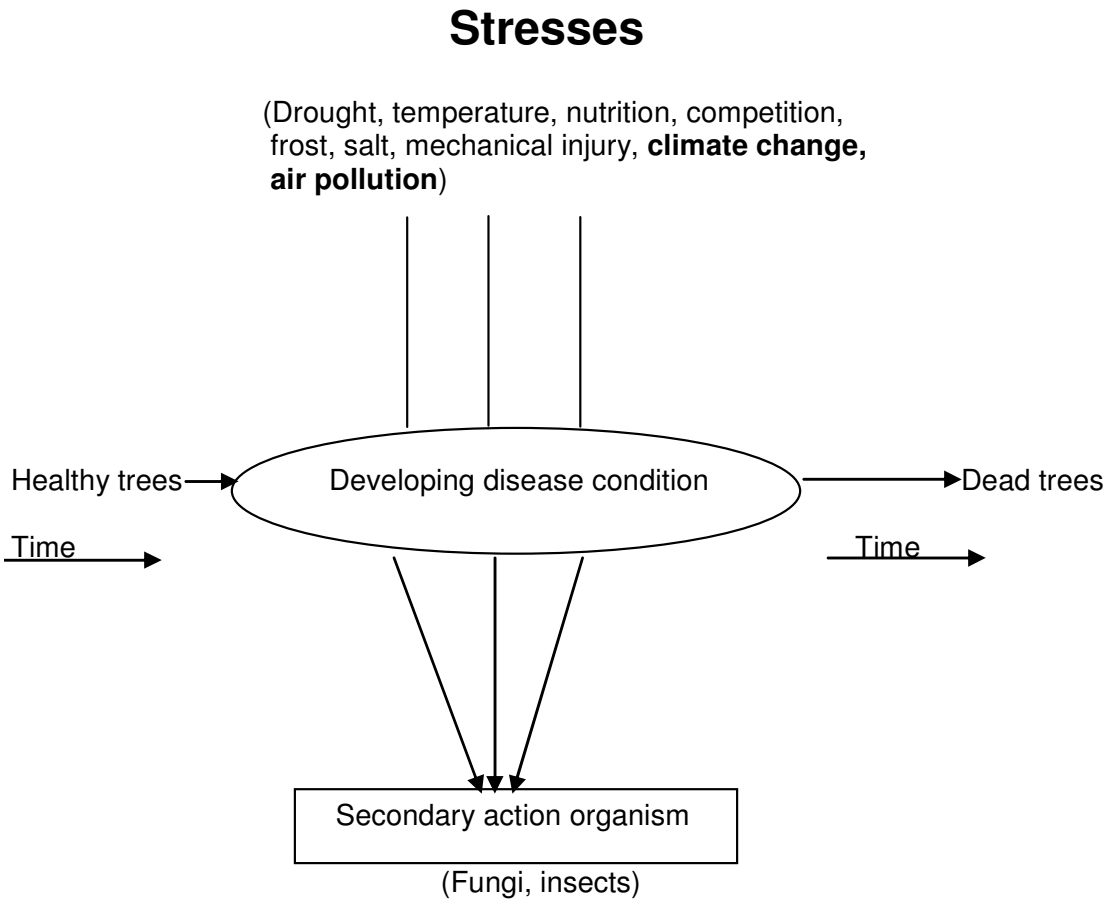


**Figure 1.** A conceptual framework for the host-stress-saprogen model (Houston, 1981).

inward decline spiral model. Within each ring are a number of stressing factors to indicate the interchangeability of the various factors. Each decline situation involves one factor from each ring. Manion (1991) also defined that definition of decline is an interaction of interchangeable, specifically ordered abiotic and biotic factors to produce a gradual general deterioration, often ending in death of trees. Predisposing stresses generally have a long term role in weakening the tree and making it more susceptible to the short term inciting factor. Once a tree has begun to decline, contributing factors, which are generally biotic stress, may kill or weaken the tree by accelerating its decline (McLaughlin, 1985). Air pollution may act as both predisposing and inciting stresses in influencing forest decline.

Decline models involve a number of interacting factors. Air pollution stress is one of the causes to explain forest decline (Figure 2). In general, air pollution changes the net carbon balance of a plant through effects on the light reactions or enzymatic functions and increased respiration from reparative activities. Short, high concentrations of air pollution can results in acute damage, but chronic exposure usually results in cumulative effects on physiological process. Gradual decreases in photosynthesis, stomatal conductance, carbon fixation, water use efficiency, resistance to insect and cold resistance were found in most of trees which are very typical symptom of air pollution stress (Smith, 1992).

In addition, air pollution loads may alter or inhibit forest tree reproduction, alter forest nutrient cycle, alter tree metabolism, change forest stress conditions by influencing insect pest, microbial pathogens and by directly damaging foliar tissue (Lovett and Kinsman, 1990).

## FUTURE PERSPECTIVE OF FOREST DECLINE

It is too early to tell how forest decline pattern and air pollution may affect the tree community and whole ecosystem. The processes of forest decline for air pollution in forest ecosystem probably occurs over long periods of time. However, there is increasing evidence that trees can adapt to air pollution. There are various studies suggesting that natural selection takes place in areas where severe stress of vegetation is occurring.

It is well known that environmental stress such as air pollution has clearly caused major evolutionary changes within species (Bradshaw and McNeilly, 1989). Air pollution can affect selection process. Air pollution, which can result in forest decline, can eliminate the most stress

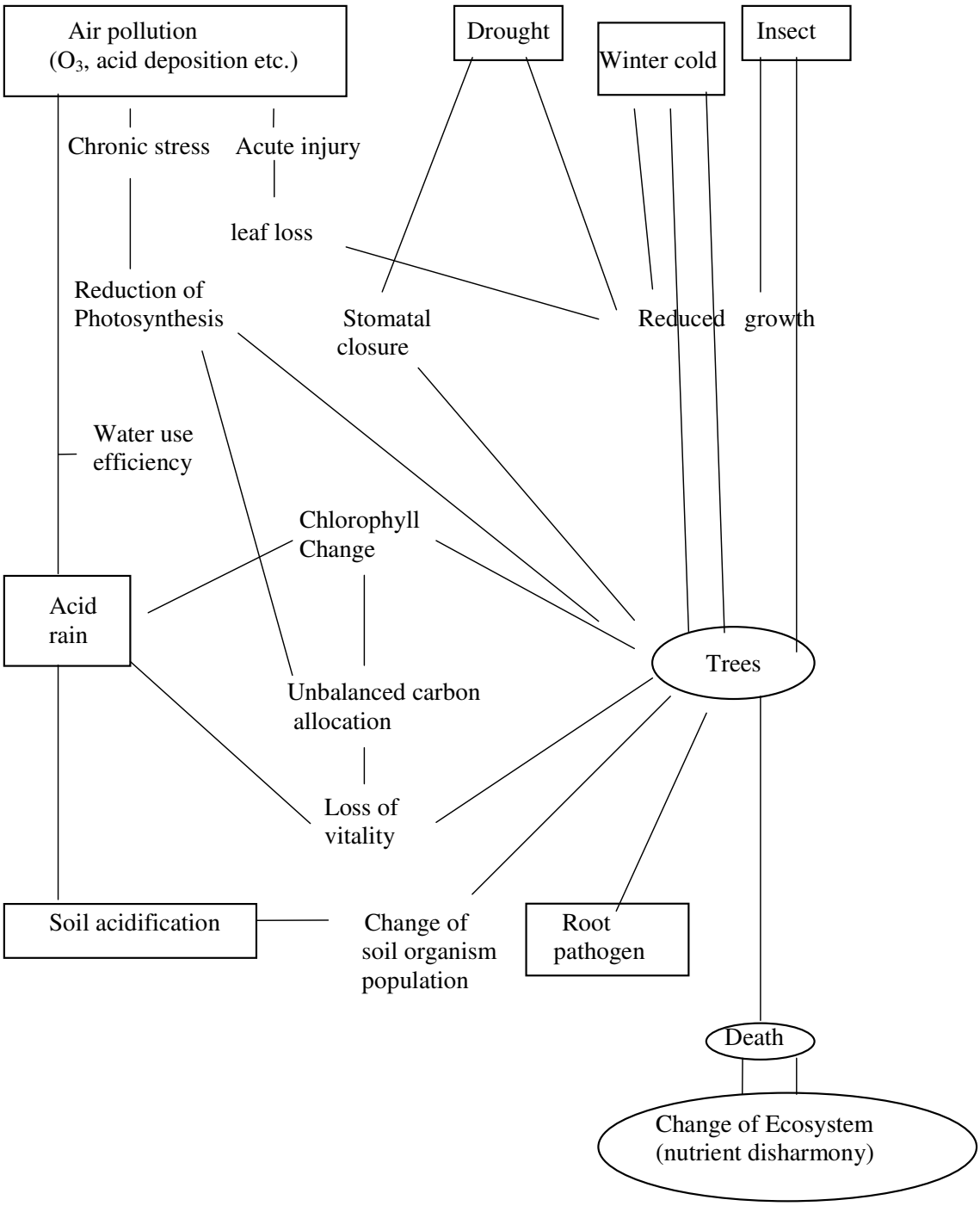


**Figure 2.** Possible model of forest decline.

sensitive genotype and give survivor to most resistant genotype. Interbreeding of these survivors makes more resistant genotypes.

It is certain that several air pollution stresses are actually involved in forest decline in both Europe and U.S. Air pollution effects on forests depend on the sensitivity of individual trees and species to the pollutants and complex interactions between trees, environment and other organism. Even though species sensitivity is important, a dominant tree might receive the greatest exposure to pollutants and show the greatest impacts; under story plants were expected to be less affected (Treshow and Anderson, 1988).

In Europe, atmosphere pollution, nutrient imbalance and alteration of winter cold resistant have been focused on causes of forest decline (Brown et al., 1987; Lucas et

al., 1988). Pollution effects on stand structure in central Europe appear high elevation. Most red spruce die back appeared at the high elevation. Red spruce decline be caused from interaction between ozone and winter cold at the high altitude. During spring and summer mean air temperature are lower on the summit than the valley or low elevation. Cold weather at high elevation comes sooner than at low elevation does. Plants in high elevation has relatively short growing season. Ozone increase winter cold sensitivity at the high elevation (Lucas et al., 1988).

In the eastern North U.S., acidic deposition and ozone have been suggested as possible cause of forest decline. Data of acid rain indicates that area has stronger acid rain than other areas (Smith, 1992). Night time and early morning ozone concentration are greater at high elevation than at low elevation sites. Daytime ozone levels are equal or slightly higher at high elevation sites (Lovett and Kinsman, 1990). High elevation sites tend to experience higher mean relative humidity. Uptake of $SO_2$ and ozone by plants also has been known to increase with greater humidity (McLaughlin and Taylor, 1981). Low air water vapor deficit induced stomatal opening and increased ozone uptake at high elevation. Even though there is still argument about the reason why forest decline is happening, air pollution is one of the predisposing and inciting factors of forest decline.

Air pollution is one of the most important types of stress that explains forest decline. Insects and winter cold have roles as contributing factor to accelerate forest decline. Air pollution stresses change physiological, morphological characteristics in the tree and soil conditions in the forest. Interaction of those factors induce reduction of forest vigor and growth, in the end, these factors influence tree death and change ecosystem.

## CONCLUSION

Forest decline in several regions of the world is an obvious phenomenon. Probably, air pollution and global warming are the one of the key factors for forest decline due to their greatest negative impact toward forest tree, stand and ecosystem. Especially, air pollution has often been used to explain forest decline. However, forest decline could not be explained by one specific type of air pollution such as ozone or acid rain, because most of the forest decline is the result of complex interactions of multiple factors. Many studies suggested that air pollution is supposed to be linked with forest decline of the world.

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