THE ECOLOGY OF FOREST DECLINE

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This paper was written as a handout for maple syrup producers in Waterloo Region

INTRODUCTION

In May of 1986 a symposium was held in Quebec for the benefit of maple syrup producers. During this conference maple decline was defined as "a disease resulting from the interaction of several biotic and abiotic causes or stress factors, acting simultaneously or in sequence so that cumulatively they gradually weaken a tree and kill it." It is therefore essential in a discussion of tree decline to consider all of the stress factors acting on the trees and it is unrealistic to ignore these other factors and immediately assume acid rain is the only problem. Although there is a large body of circumstantial evidence to suggest that acid rain is a factor in forest decline the intent of this paper is to concentrate on the other environmental forces that are involved in decline, either alone, in conjunction with each other, or in conjunction with acid precipitation.

HISTORY

Far from a new phenomenon, (decline) has been observed for at least two hundred years in Europe and nearly a hundred years in North America.

In North America, sugar maple declined, especially in urban areas, around 1910, again in the 1930's and more recently in the 1960's; white ash in the northeast since the thirties; birch in the northeast between the early forties and the late sixties; beech in relation with beech bark disease since the early forties in the northeast.

In Quebec, black ash declined severely from 1927 on; sugar maple declined in Beauce in 1934; eastern hemlock has declined since 1975 and several varieties of oak trees, butternut and american beech have been reported to be declining since 1983 in the Outaouais valley. Among the most important cases observed in Quebec are two already mentioned as North American problems: birch decline and beech bark disease. Cases of sugar maple decline were observed in northern Wisconsin in 1956-57 and in Ontario in 1952, 1957-58 and 1976-77. Northeastern Ontario maple stands have been suffering in recent years from a new wave of decline similar to that now affecting Quebec maple stands. Sugar maple has also been declining in northern Vermont for some time.

ABIOTIC FACTORS OF TREE DECLINE

CLIMATE

One theory which has been put forth to explain the various instances of decline is that by Dr. Kenneth Watt of the University of California. He states that many of the weather stations that have been monitoring environmental conditions are now influenced a great deal by urban development and growth creating an "island effect". These weather stations are therefore recording higher temperatures than actually occur. Using data from isolated stations he draws the conclusion that although no one has been able to directly correlate tree dieback with peaks of acid deposition there is a direct correlation between peaks of decline and groups of years with lower than average temperatures during the summer growing season. Also contrary to popular opinion, he says that the earth is not going through a general warming trend but is becoming hotter at the equator and cooler near the poles. Furthermore he feels that the effect of this cooling trend is being felt more strongly at higher altitudes. This would tend to explain why tree dieback is more serious in areas at high altitudes such as Camel's Hump in the U.S. Nor is a very large temperature change required to create havoc with vegetation:

" ...it takes a drop of 6 deg. C. to move from the top to the bottom of the warm temperate life zone: A temperature drop this large extends from halfway up the cool temperate life zone to the margin between the subpolar and boreal belts. Or, in high altitude or high latitude habitats, a sustained mean monthly temperature decrease of 3 deg. C. would produce a profound change in the species composition of a plant community. A ten deg. C. sustained drop in annual mean temperature is equal to the maximum range of annual mean temperatures encountered on this planet over the last 100,000 years."

This theory can also explain the order in which trees die. That is, in many decline situations, those species which are on the northern extent of their range would tend to die out more rapidly than those on the southern part of their range. He uses Camel's Hump as an example as the more southern red spruce is more seriously affected by dieback than the more northern fir. In Quebec too, the maple growing at higher altitudes with yellow birch on northern podzolic soils is more seriously affected than maple at lower altitudes growing with basswood on more southern brunisolic soils.

This theory of temperature variations being involved in decline has been confirmed by the Ministry of the Environment. It is a well-known fact that years in which temperatures in the months of May and June and in the months of September and October are below normal, and particularly when both of these periods are below normal in the same twelve month period, are severely detrimental to tree health. It has been documented that in the period 1920 - 1940 abnormal temperature conditions occurred 9 times, in 1940 to 1960 they occurred 4 times, and from 1960 to 1980 they occurred 15 times.

SITE

Let us look at the site requirements of trees using sugar maple as an example. Sugar maple is a fussy tree. Through work carried out in the last five years by the Ontario Institute of Pedology under contract from the Ontario Ministry of Natural Resources, we now have more information on the site requirements of our major tree species than we ever had before. Sugar maple does best on soils ranging in texture from sandy to silty and with moisture available at a depth of approximately one metre. When it grows on soils approaching either gravely or clayey, or with moisture at depths exceeding 150 centimetres or closer to the surface than 50 centimetres its growth capability drops off dramatically. Therefore when one is dealing with clayey soils one can often expect a lower resistance of the maple trees to stresses. Even where better textured soils have excessive or less than adequate moisture, problems may occur. I make a distinction here between sugar and black maple, black maple being more adaptable to heavier and wetter soils.

Similarly, variations in the type of soil in Ontario warrants some comment. The pH of the soil in many of the decline sites in Muskoka was below 4.5, very acidic. But one must remember that these soils are naturally acidic podzol soils formed in parent materials originating from granite. Hence they have a very low buffering capacity, or the ability to neutralize acid, and they are inherently low in "exchangeable bases", therefore inherently low in fertility. On the other hand, soils south of the shield are formed in material derived from sedimentary rocks such as shales, sandstones and limestones which have a high content of magnesium and calcium carbonates. These soils therefore commonly have pH's of 7 (neutral), have a much higher buffering capacity, and are much more fertile. These differences are often ignored in discussions of decline.

BIOTIC FACTORS OF TREE DECLINE

PATHOGENS (ROOT DISEASES)

Armillaria mellea SHOESTRING ROOT ROT

Throughout most of the literature dealing with tree decline of hardwoods, the most common disease mentioned as being significant is "shoestring root rot" or "honey fungus", *Armillaria mellea*, and consequently I will use this disease as an illustration of tree/disease relationships. This fungus commonly attacks most hardwood trees and some conifers as well. It is one of the most common root diseases and can be found in most woodlots. As has been documented in the decline situations in Quebec;

"the presence of this fungus indicates a debilitated condition of the tree from some prior cause . This stress can take any number of forms including drought, defoliation, or mechanical injury and whereas without the disease the tree would recover, with the disease the tree eventually dies."

In the past, the disease was always known as *Armillaria mellea*, but as is typical in the forestry profession it is not unusual for biological names to change. In 1988, we started to see the disease referred to as *Armillaria obscura*. The reason offered for this change is that whereas it was always thought that this common disease was one species, it is now considered that there are eight different subspecies of this fungus. Because of this variation in the species, it is also quite likely that the different subspecies have different characteristics. This is important to us because with different subspecies it is likely that there are strains that will be more virulent than others and whereas some strains attack weakened or stressed trees, some strains may attack healthier trees. Normally, the fungus attacks a tree through a damaged root or through root contact. It is possible that a more virulent fungus may have greater ability to infect healthy roots.

Furthermore, it has been found that this fungus prefers acidic soil conditions, preferring pH's between 4.5 to 5.5. This is important because of the implications regarding acidification due to acid precipitation. If soil pH is being reduced through acidification, does it mean that trees are more vulnerable to *Armillaria* infections?

In the early stage of infection, the fungus grows under the bark by what are called mycelial fans, a whitish fungal layer which forms between the bark and the wood. Later rizomorphs appear which are the black or brown shoestrings. In the fall the fungus produces the honey mushrooms around the base of the tree. These produce spores to spread the fungus and later in the fall the mushrooms dry up. The most interesting characteristic about this disease is that it spreads through the soil by the rizomorphs which infect new root systems through injured roots. Most other fungi spread mainly by spores.

The most serious cases of maple decline that I have seen have a very high incidence of *Armillaria* infection. When one looks at two local sites, several differences are apparent. On site 1 in Wilmot Township, the fungus is attacking trees in an area about an acre in size. When the bark is chipped away, the mycelial fans can be seen and when exposed to the light, they begin to turn brown. On this site, in the fall of 1988, there were almost no mushrooms produced. On site 2 in Woolwich, on an infection centre of about two acres, exposed mycelia remained bright white, and mushrooms were prolific. Does this then mean that the two sites are infected by different subspecies of the fungus?

On site 1 in Wilmot soil pH's were 6.5, 7.0+ and 7.0+ in three separate samples. On site 2 in Woolwich, soil pH's were 6.0, 7.0 and 6.5. It is difficult to say then that soil acidification is contributing to the spread of the fungus on either site because soil pH does not appear to be abnormally low. It is likewise difficult to say what factors may be stressing the trees and causing the infection, as both sites are productive sites, being on fine to very fine loamy sands with good drainage. Outside of the infection centres, trees are normally healthy.

If trees are left uncut the fungus causes a yellow stringy rot in the wood. This will reduce the value of the wood for fuelwood or logs. However, if as has been recommended, leaving the trees to die before cutting will slow the spread of the fungus, the wood loss may be a small price to pay. It may also be that some declining trees recover and should be allowed to do so.

In terms of additional control measures for *Armillaria*, none that are effective have been found. Attempts to remove old root systems have not worked, likewise no chemical controls have been proven effective. Management practices such as maintaining a stand at a relatively constant, optimum stocking rather than allowing the stand to become overstocked and then reducing stocking drastically may be beneficial. Keeping a good stocking of vigorous young growth rather than overmature trees should also help. However, once an infection centre becomes established, trees of all sizes may be affected.

Fomes annosus

Fomes or annosum root rot is a common root disease attacking conifers, particularly red pine. Unlike *Armillaria*, *Fomes* is an alkali-loving fungus, often becoming a problem in stands where pine has been planted on sites unsuitable for the species. An example is where red pine is planted on eroded sites in southern Ontario. This species is native on northern sites where soils are derived from granite materials. In the south, however, soils are derived from shales, limestones and dolomites which are rich in calcium and magnesium carbonates. These free carbonate materials are normally removed from soil profiles by weathering processes. On an eroded site, because the normal soil profile has totally or partially been removed through erosion, the trees are in contact with the calcareous parent materials in which the original soils were formed. This condition results in the trees having difficulty absorbing nutrients which produces off-colour foliage and makes the trees weak and susceptible to pathogens.

In a plantation, it is normal for the root systems of trees of the same species to be joined or grafted underground. This fungus usually infects trees through the root system which is exposed by thinning a stand and leaving fresh-cut stumps unprotected from the fungus spores. The fungus grows through the root system of the cut tree and into the root system of the live tree through the grafted roots. The disease then causes a white, stringy pocket rot, with characteristically resin -soaked wood, which weakens the tree, often resulting in windthrow or stem breakage.

In the fall, in damp weather, the fungus produces woody sporophores at the base of infected trees and stumps. The spores produced transfer the fungus to other stumps.

The control of this disease is to clear-cut all infected trees and to cut sufficient numbers of live trees around the infection centre that the old root systems die before the fungus spreads out of the clear-cut area (at the rate of a metre per year). Cut surfaces of the stumps are treated with borax within ten minutes of cutting the trees, to prevent further infections.

TREE PHYSIOLOGY (AND DROUGHT)

An understanding of the production, storage, and utilization of the tree's starch reserves helps explain the mechanism of tree decline whether by atmospheric or environmental problems, pathogens or insect defoliation.

In deciduous trees, the carbohydrate stores are emptied shortly before the leaves begin to unfold, the substances being sent to the buds and later to the new shoots. To do this, the stored starches are converted to sugars which are then translocated. About a third of the reserve materials serve for the building up of assimilation surfaces (leaves), which very soon operate with a positive balance and in their turn contribute to the further formation of the leaves and shoots in the new growth. After the foliage is completely formed, it supplies the tree with photosynthates. As a rule flowers and developing fruit are supplied preferentially, next in order is the cambium, and last the newly forming buds and the depots (storage areas) of starch in roots and bark.

From this it can be seen that any condition which interferes with carbohydrate formation or drains the tree's food reserves, such as defoliation or drought, will severely restrict root growth as roots are low in the list of priorities for energy reserves. As an example, the drought of 1988 may have severe impact on trees for the next several years. Such a drought, besides damaging roots, causes photosynthesis or carbohydrate production to essentially stop. However hot weather tends to speed up respiration or food consumption. The combined effect leaves the trees with a decline in food reserves, and a root system poorly equipped to recover from the damage. The resultant root injury also creates entry points for root pathogens such as *Armillaria* and the tree is poorly equipped to compete with the infection. Once the root system is damaged, crown dieback follows.

TREE PHYSIOLOGY (COMPARTMENTIZATION)

Many landowners are familiar with the stain that occurs in wood when trees are tapped. When trees are injured they wall off the injury with a barrier of mineral stain. This is called compartmentization. The effectiveness of the barrier depends on the vigour of the tree and the virulence of a fungus, if a fungus is involved in the injury. Trees are able to lay down a very effective barrier radially, by sealing off the injury at a growth ring or growth layer. They can also fairly effectively seal off an injury laterally at ray cells, the soft cells that make some woods easier to split. Because wood is designed to translocate mainly vertically, the trees have difficulty making a barrier to stop vertical spread of an injury. This is the reason the tapping injury makes such a long stain column up and down the stem, but very little in other directions.

When a fungus such as *Armillaria* or *Fomes* affects the live wood of a tree and causes part of the stem to be compartmentized, the result is a loss of stored food reserves because of the energy required to fight the infection, and a loss of storage capacity to the tree as part of the stem is lost to use by the tree. When trees are under stress by environmental pressures and a fungus is competing for living space within the tree, the tree then becomes a candidate for decline.

DEFOLIATION

Defoliation which causes the trees to send out new leaves not only reduces food production temporarily, but causes the conversion of starch to sugar to provide the energy to produce this new foliage. Again this reduces starch reserves and in the roots produces conditions suitable for the spread of fungus. The depleted starch reserve condition was the most consistent condition that was observed in the Muskoka decline. Actually, a consistent finding in the Muskoka decline report, and it is one of the best reports that I have seen on a decline situation (by our own Ministry of the Environment) was that all declining trees showed low starch reserves. This led the researchers to conclude that although acid deposition may be playing a part in stressing the trees, the primary causes of decline were defoliation and drought which resulted in this starch depletion.

HUMAN INTERVENTION

HISTORY

Stand history can play a part in stand decline. For instance, if a stand is allowed to become overstocked and competition for space, nutrients and moisture is severe, trees will be weakened and pre-disposed to stress caused by weather or other factors. On the other hand too much harvesting or poorly carried out harvesting or thinning can be just as detrimental as overstocking. Some harvesting as with *Armillaria* or *Fomes* may contribute to the build-up of pathogens in the stand.

It is also easy to see why grazing, which compacts the soil around the roots, causes root injury and reduces tree growth rates, can pre-dispose trees to decline and aid in spread of root rot diseases.

HARVESTING (THINNING)

An interesting fact about *Armillaria* is that it feeds on sugars in the wood of most hardwood trees. When a tree that is infected with this fungus is cut down, the tree no longer is able to seal off the infection and the root system is inundated with the disease. This abandoning of entire, healthy root systems is a condition that man has artificially created. It may be for this reason that the recommendation has come from decline studies in Quebec that thinning should proceed very cautiously in a decline situation or when defoliation or drought is anticipated. Cutting seems to act pathologically and increase the advance of the decline.

Furthermore, regarding thinning, it has sometimes been said that some stands and some trees do not respond to thinning. On the contrary, it may well be that the thinning or for that matter fertilization, produces a growth response in the trees. The growth response causes the trees to convert starch in the root systems to sugar which is then translocated throughout the tree to produce additional crown growth at the expense of root growth. This is one reason why sap sweetness and production increases after thinning or fertilization. It may also partially explain why only vigorous trees with correspondingly high starch reserves responded to fertilization in a study done between 1976 and 1980. Unfortunately, this mobilization of sugar improves conditions for the *Armillaria* and the disease which may have been laying dormant in the root system may increase to the point where the tree begins to decline.

Thinning stands when trees are in decline, when an insect outbreak is anticipated or in the presence of severe or extreme weather conditions may therefore be detrimental.

The opposite is true in the case of *Fomes* as described above. To control this disease, clearcutting with stump treatment is recommended.

FERTILIZATION

When I am discussing tree decline with a farmer, the first question he usually asks is whether he should apply lime to counteract acidification. Studies on soil treatments have found that adding calcium or lime to a soil can increase the decomposition of the organic matter in the soil and result in a loss of nitrogen. Also lime should be incorporated, difficult to do in a woodlot. Similarly, upsetting soil balances such as adding too much calcium can tie up other nutrients such as potassium inducing a nutrient deficiency. It is therefore important to know what is present and what is lacking in a soil and in foliage before adding materials. Also the nutrient requirements of trees are less well documented than the requirements of agricultural plants. Fertilization that has a tendency to reduce pH such as high nitrogen applications should be avoided. Some areas should be left untreated to compare to the treated area and to monitor any natural stand recovery.

Nevertheless, the addition of fertilizers, either chemical or organic may have some benefits to help trees to better deal with short term stresses. Current recommendations are for fertilizers with no nitrogen but with adequate phosphorus and even more potassium such as 0-8-18 applied at rates from 350 to 550 pounds per acre. However, their use should not be seen as a cure-all to the extent that other problems such as site problems are ignored or misunderstood.

SUMMARY

This report is intended to tie together some of the stress factors acting on trees and some of the physiological responses to these stresses. Trees are part of a forest ecosystem. In order to understand what is happening to our forests at the present time, we must first understand how trees function, how a forest functions, and how trees and forests interact with their environment. We must view problems from an ecological perspective.