Tree Reactions To Chlorine Gas Exposure

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Chlorine gas exposure can damage trees. This publication reviews tree reactions to chlorine gas exposure. This is not a toxicology or environmental dosage review, but is designed to help tree health care professionals understand the potential injuries sustained by trees and other landscape plants when exposed to chlorine gas.

Tree reactions to chlorine gas can take many forms. The reactions can be summarized into four primary reactions: 1) a tree accidentally avoids chlorine gas by season of year, topographic position, crown height, etc.; 2) a tree tolerates chlorine gas by detoxifying, oxidizing, compartmentalizing, or incorporating (a stress); 3) a tree shows an temporary (elastic) strain from changing physiological functions; and/or, 4) a tree shows a permanent (plastic) strain from injury.

A Cute Leaf

Acute chlorine damage in trees is primarily confined to leaves, buds, and rarely tissues beneath lenticels on twigs. Chronic exposure leads to a buildup of various chlorides in tissues and on surfaces. Close to the chlorine gas source, or at high exposure dosages, leaves are killed, browned, and stay attached to the tree for some time. Figure 1. Leaf tissue at high exposure dosages can present bleaching within 24 hours and can be dead within 48 hours. Under high chlorine gas concentrations, buds are also killed and brown-out. Twig tissues are damaged at higher concentrations and exposure durations. As concentrations and durations of exposure build, trees can be killed. Figure 2.

Low to moderate acute exposures to chlorine gas initiate tree reactions at the site of contact on the tree, not systematically. As the concentration of chlorine gas declines and as distance from the source lengthens, most tree reactions to chlorine gas are exclusively concentrated in the leaves. Whether trees hold or lose their leaves, they are more prone to other pests and stresses after chlorine gas caused damage. Figure 3. At low doses, no visible damage may occur, but over the next few months of the growing season leaf epinasty can occur. Epinasty is the twisting, cupping, or curling of developing leaf blades and petioles. Even though no visible injury was sustained, exposure has initiated growth disruption through auxin transport damage and generation of ethylene.

Seasons

Tree reactions to moderate and low exposure dosages of chlorine gas generate a series of symptoms which change over time and can progress from one set of reactions to the next. Tree reactions will also vary by tree life-stage and season. If leaves are not present, less visible reactions occur and less injury can result. The Spring time period when leaves are expanding is the worse time of year for exposure. The next most critical time for exposure is any time in the rest of the growing season after full leaf expansion. Foliage damage in late Summer and Fall may have relatively less impact because exposure accelerates normal senescence and abscission processes. The Winter dormancy period, with accompanying lower temperatures, no deciduous foliage, and trees in a resting phase provides the least potential injury. Evergreen trees under warm day and night temperatures can be severely damaged even in Winter. Older-aged needles are lost first. Figure 4.

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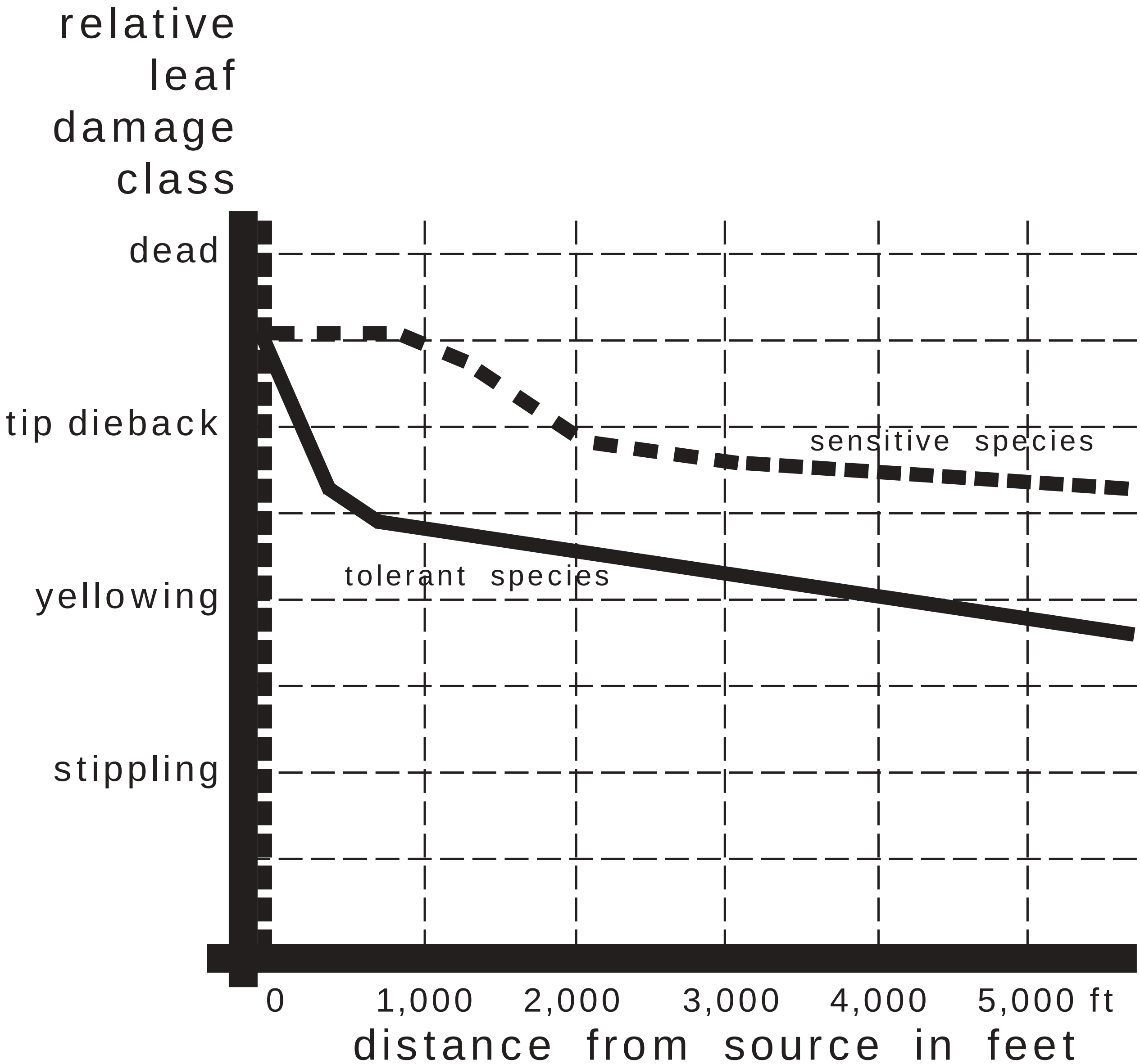

Figure 1: Historic leaf injury present for a sensitive and tolerant gymnosperm species downwind of a chlorine gas source after 2 months from exposure. (after Schreuder & Brewer, 2001)

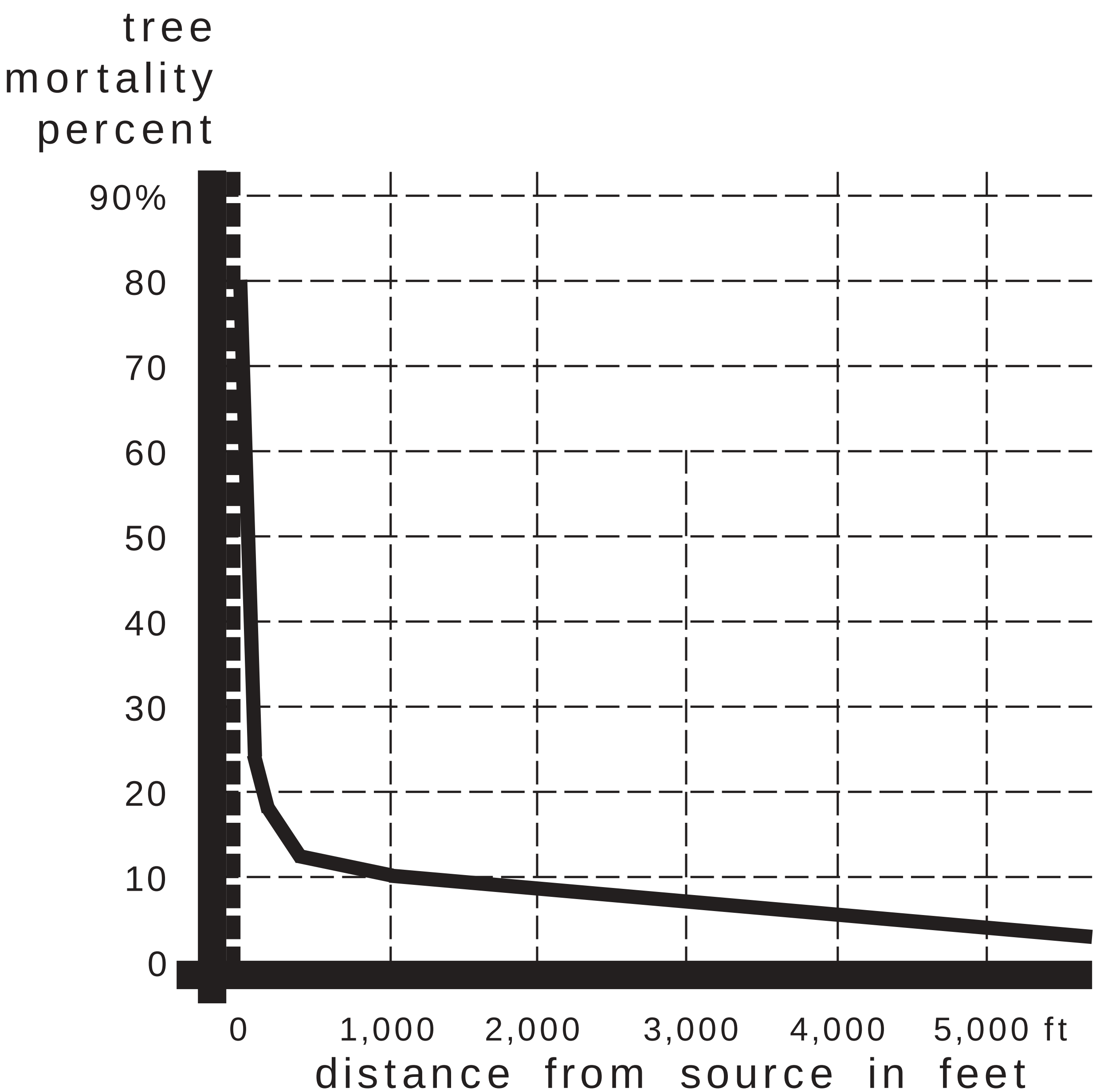

Figure 2: Historic mortality curve for a sensitive gymnosperm species downwind of chlorine gas source after 3 years from exposure.
(after Schreuder & Brewer, 2001)

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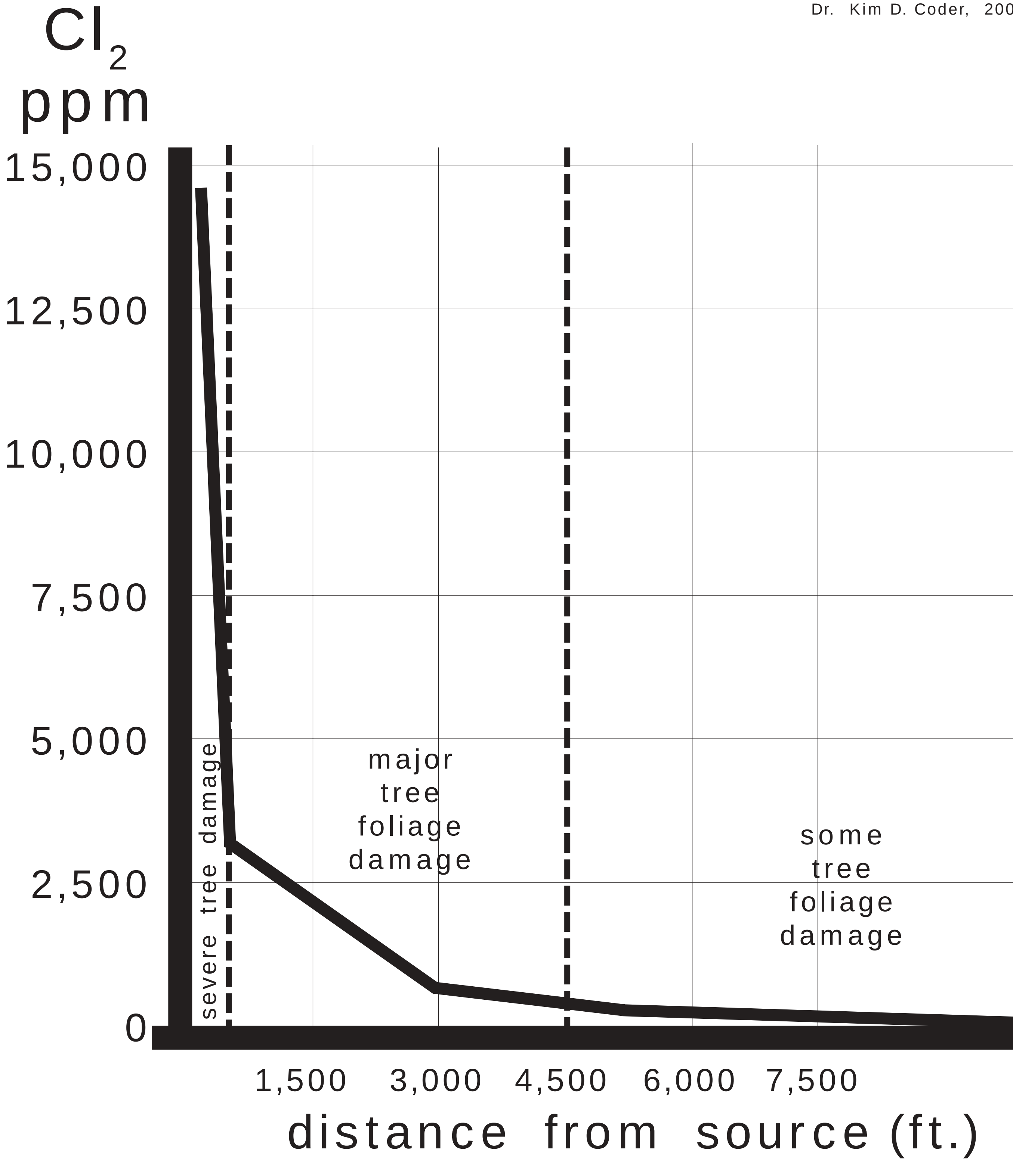

Figure 3: Historic dilution curve of highest chlorine gas concentrations measured in ppm over distances downwind from the source in a location with constraining topography. Dotted lines separate severe, major, and generalized damage zones.
(5 ppm at 30,000ft downwind)

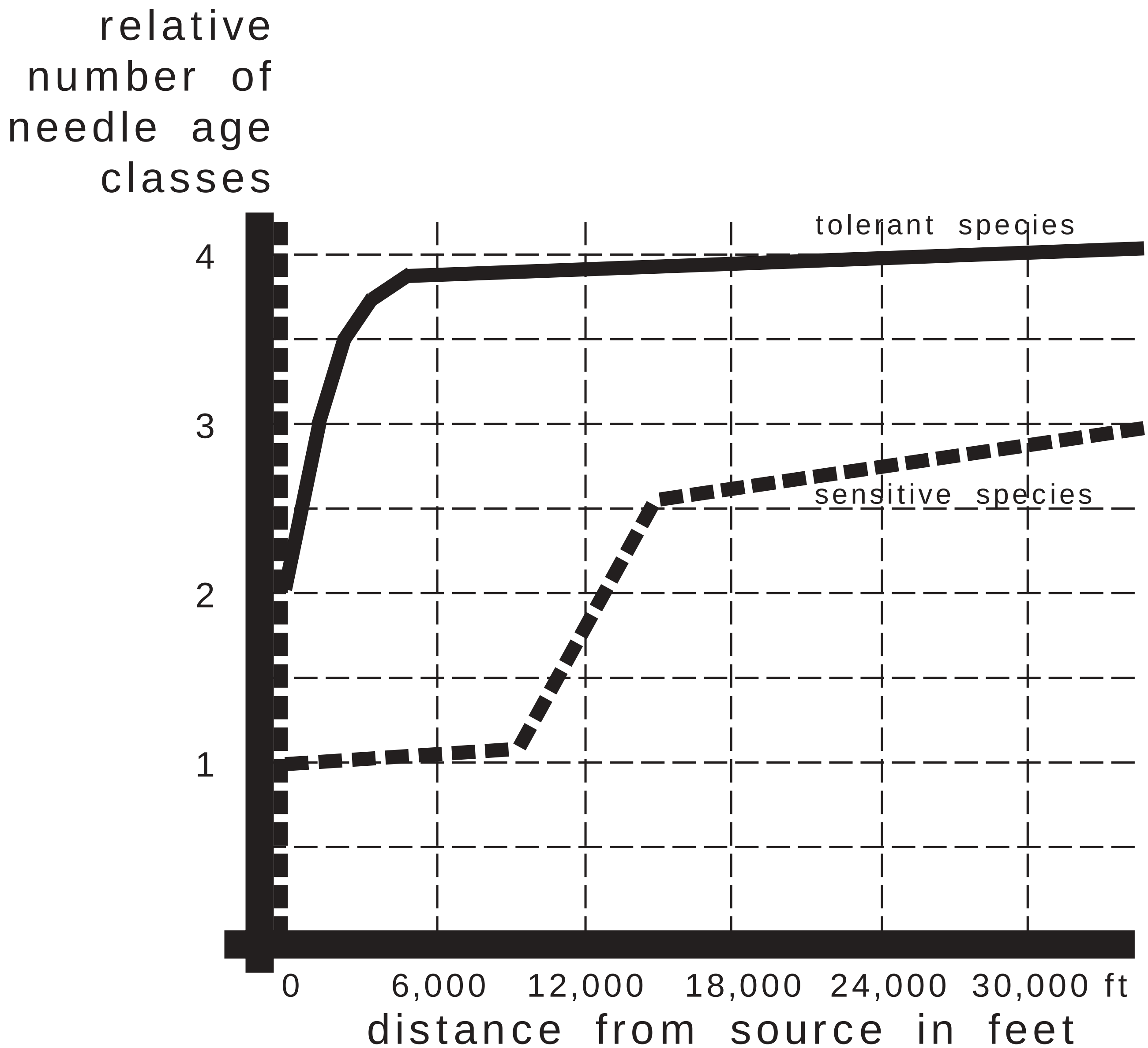

Figure 4: Historic needle age classes present for a sensitive and tolerant gymnosperm species downwind of chlorine gas source after 2 years from exposure. The fewer age classes, the more damage from exposure.
(after Schreuder & Brewer, 2001)

Damage Trail

Chlorine gas exposure can be seen to follow a distinct and rapid damage pathway in tree leaves. The first damage is on the underside of the leaves in cells surrounding the stomates. Damage is next apparent in the leaf mesophyll (photosynthetically active) cells adjacent to the air spaces just inside the stomates. The cellular damage expands through more and more of the mesophyll cells. The next impacts can be seen in the more densely packed leaf palisade cells in contact with injured mesophyll cells. Damage appears now on both upper and lower leaf surfaces. All the thin-walled cells of the leaf begin to crumple and collapse, forming more air spaces just below the tough epidermis (surface) cell layer. Water can begin to accumulate in open spaces and appear to saturate leaf tissues. Finally epidermal cells start to pull apart from each other. As the damage progresses through the leaf, veins are the last to be effected.

Acid & Bleach

Chlorine gas is absorbed in the water layer covering the mesophyll cell walls inside the leaves. As chlorine gas is dissolved in this water, hydrochloric acid (a strong acid (HCl)) and hypochlorous acid (a bleaching agent (HOCl)) are formed. The cell wall areas enclosing living tissues become highly acidic. The pH of this water has been measured as low as a pH of 1.8 after chlorine gas exposure, which is similar to battery acid. Water on the exterior surfaces of the leaf do not have a significant impact on leaf damage. Figure 5. As the leaf initially sustains damage, stomates are closed and wilting occurs -- which tends to reduce further leaf damage.

Death By Chlorides

The living systems in the leaves attempt to oxidize the chlorine into chlorides as long as food supplies are available and membrane permeability remains stable. Any chlorides produced are pushed out of the cells and passively transported to evaporating surfaces such as leaf tips, edges and stomates. These chlorides can build-up, representing high salt loads on leaf surfaces. The chlorides pull water out of the living cells causing severe desiccation and more physical distortion of cells. Chloride accumulations in the soil are particularly damaging to tree roots and disrupts water uptake.

Dying Cells

Internal damage accelerates, involving more biological and structural systems within the leaf. Generally, damage from chlorine gas starts with a reduction in photosynthesis and an accumulation of acidity, bleaching and oxidized products in the leaf. The drier the leaf is when exposed, the less damage it sustains because its stomates are more likely to be closed. Drought conditions leading into and during exposures reduce potential damage from chlorine gas entrance into the leaf. Once chlorine gas enters the leaf, less internal water leads to higher concentrations and less dilution of damaging agents which, in turn, leads to increased damage. An additional interaction is the light environment during and immediately after exposure. Darkness during and after exposure to chlorine gas reduces damage over full sunlight conditions. Even cloudy conditions reduce damage compared with full sunlight. Figure 6. All damaging circumstances conspire to make the leaf less resistant to more exposure.

As more leaf cells die, larger damaged areas are formed between the veins. All living cells surrounding damaged areas progressively fail in compartmentalizing damaging materials and damaged cells. This disruption and dysfunction in the leaf generates a reduction in the amount and quality of food produced and transported, as well as messing-up growth regulator production and transport. Susceptibility to pests and injury increase as defensive capabilities decline and structural units are compromised.

Conclusions

Tree reactions, both internally and externally, generate growth and health problems with chlorine gas exposures. Understanding tree reactions and recognizing symptoms are key to formulating tree health care prescriptions.

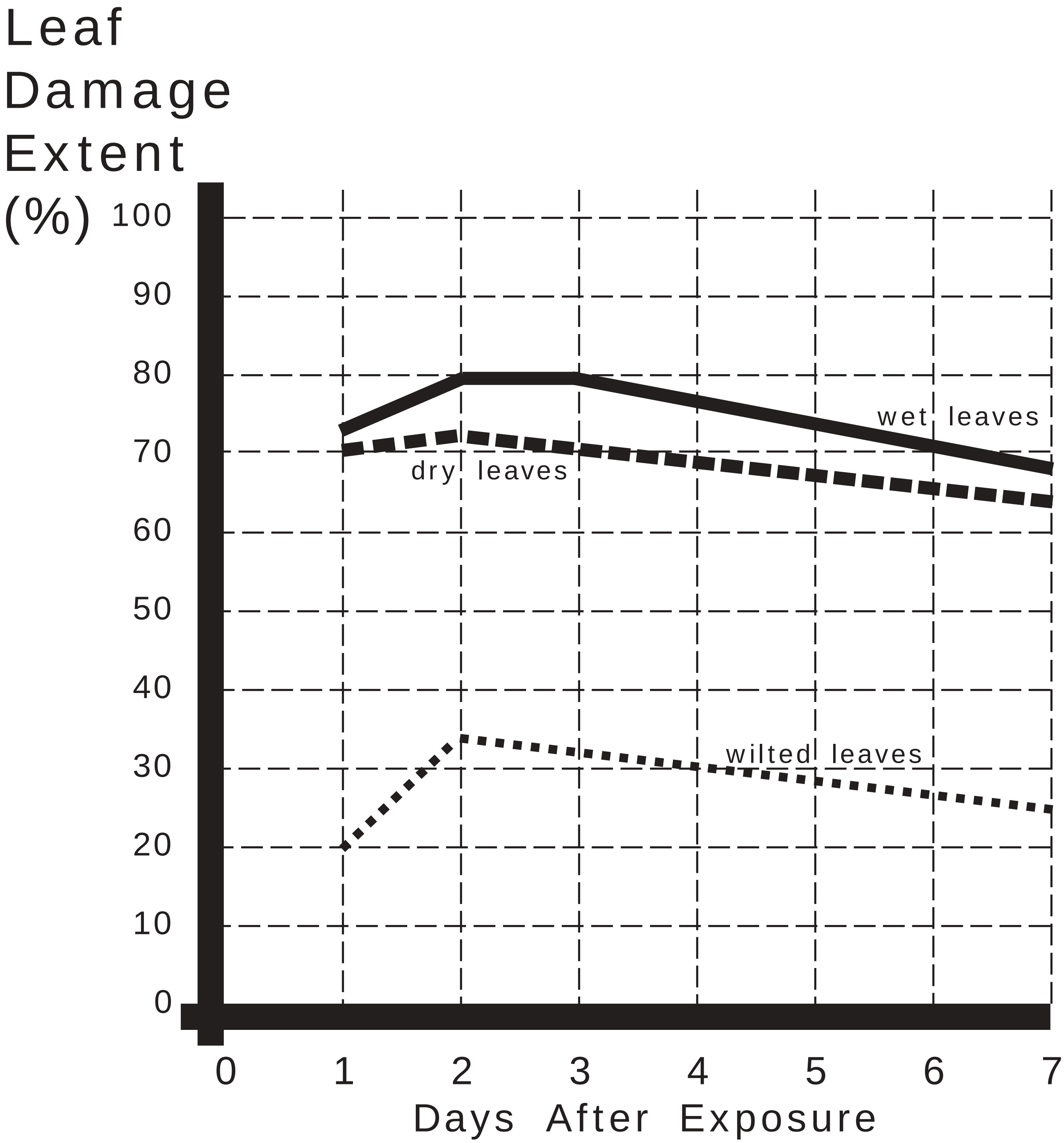

Figure 5: Laboratory chlorine exposure experiment examining plant leaf damage (100% is complete leaf damage and 0% is no leaf damage) over a one week period for three leaf conditions at exposure: wet, dry, and wilted. Chlorine gas exposure was 20 ppm for 10 minutes. (after Griffiths & Smith, 1990)

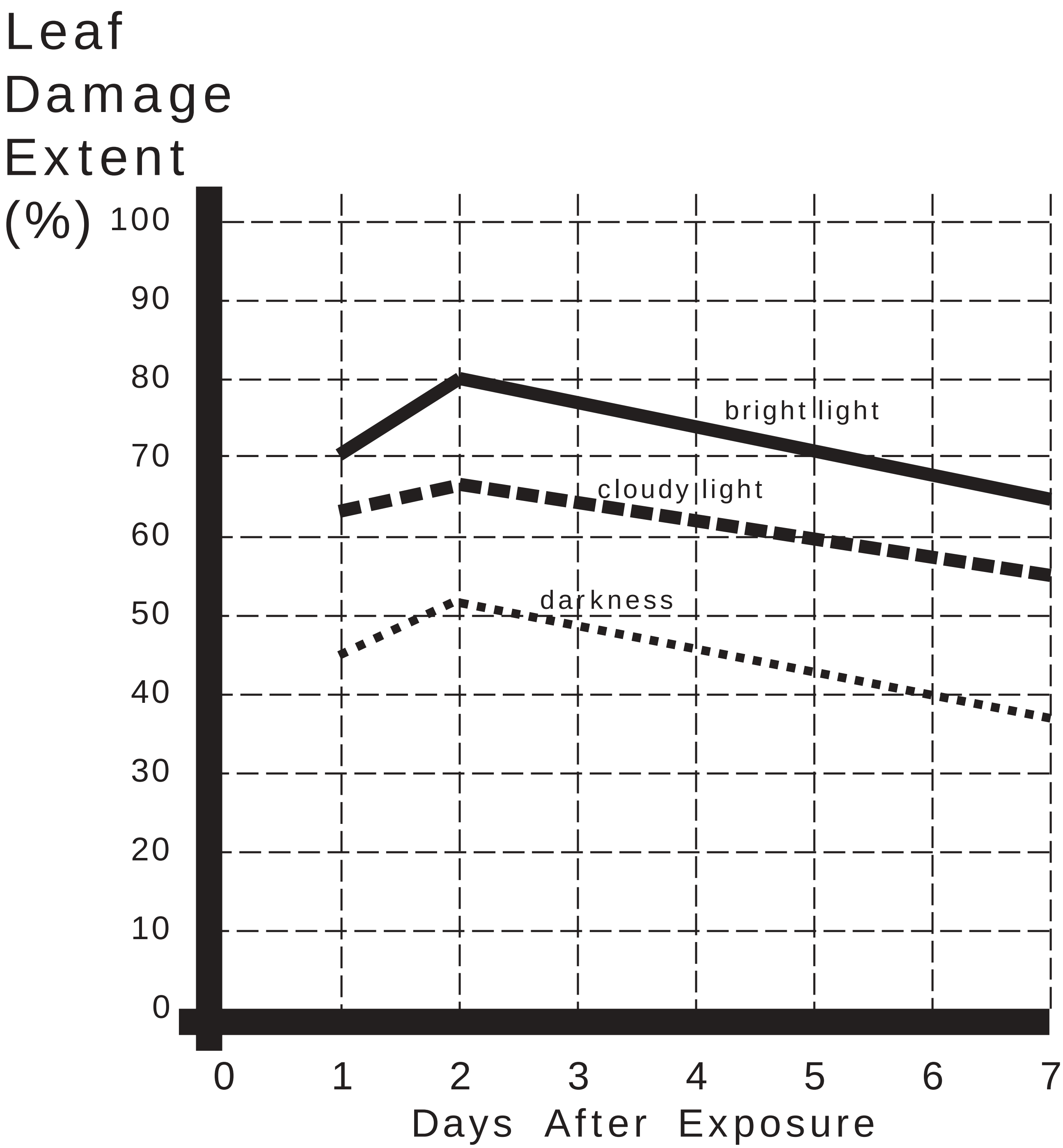

Figure 6: Laboratory chlorine exposure experiment examining plant leaf damage (100% is complete leaf damage and 0% is no leaf damage) over a one week period. Chlorine gas exposure was 20 ppm for 10 minutes under three light levels.
(after Griffiths & Smith, 1990).