# The Diagnostic Process

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Disease diagnosis─ determining the cause of a tree disease or disorder, is like doing the work of a detective. It involves examining available evidence and considering contributing factors. Diagnosis is usually based on visible evidence: symptoms and signs. Symptoms are defined as changes in the normal growth and/or appearance of a tree in response to pests, injury, tree-care practice, climatic event or environmental degradation (site disturbance or a combination of factors. Signs are evidence of the pest/pathogen, or evidence of pest activity.

Diagnosis is the process that leads to the determination of the causal agent of a pest problem (insects, disease, etc.), disorder (abiotic) or decline. It begins with the recognition of changes in the plants normal appearance or growth. The practitioner must be able to identify the plant, know when something appears abnormal, and what to look for in the way of telltale signs and symptoms and other factors.

**SYMPTOMS:**

**General:**

- death
- decline – premature and progressive loss of health
- abnormally slow growth, poor shoot elongation

**Foliage:**

- distortion
- galls (abnormal structures).
- stunting, sparseness, small leaves
- premature leaf drop
- wilting/browning
- leaf tip dieback, marginal leaf burn or leaf scorch
- chlorosis, bronzing, silvering
- interveinal chlorosis (yellowing between leaf veins)
- stippling (yellow spotting)
- bronzing or bleaching,
- early fall coloration
- defoliation, tattered or chewed foliage, leaf mining
- blackened, sticky foliage
- leaf spots, blotches or dead areas
- tufted foliage

**Trunk, stems, branches:**

- dieback (death) of buds, shoots, branch, entire tree
- brooming
- distortion of plant parts, galls
- cankers, lesions, sunburned
- bark bark lose or sloughing off

- bleeding: wet spots, bleeding, oozing, slime flux. pitch flow (resinosis)
- cracks, deep fissures
- vascular discoloration
- decay
- epicormic sprouts (shoots growing from the bark of older branches)
- lack of root-flare

**SIGNS**:
- eggs, egg cases, egg masses, cast skins, mummies, cocoons, pupal cases.
- webbing, tents, silk.
- holes in bark, leaves
- boring dust (frass), wood shavings, exit holes.
- tunnels under bark, mines in leaves.
- frass, fecal specks honeydew, sooty mold,
- white, cottony or wax-like material, spittle.
- pitch tubes, pitch masses, resinosus.
- conks and mushrooms
- mistletoe
- powdery mildew, rust
- mycelial mats, felts, rhizomorphs
- slime trails
- gnawing damage
- fruiting bodies: conks and mushrooms
- mistletoe
- mycelial fans, rhizomorphs, felts

**Diagnostic questions**:
- determine species/cultivar and relative age
- does the species have a recognized pest susceptibility
- assess health
- note symptoms and location in tree
- when were symptoms first noted? did symptoms develop suddenly or gradually?
- symptoms patchy or uniform?
- one tree or many affected?, one or more species involved?, onset of symptoms sudden or gradual, dead trees nearby?.
- are symptoms limited or widespread, uniform or irregular, symptoms spreading or static
- more than one species involved?
- are symptoms chronic?
- are symptoms increasing?
- age of foliage affected?
- consider recent or continuing climatic event, e.g., frost, drought, high humidity, wind, etc.
- assess site conditions: topography, slope and aspect, exposure to wind, full sun or shade
- check irrigation frequency, duration and drainage, reclaimed water involved?
- irrigation water collect at the root-flare?

- Recent changes in soil moisture levels: diversion by pavement, drains, soil cuts, fill soil, etc.
- assess soil conditions: depth, texture, structure (bulk density), pH, nutient imbalances*,
- impervious layers, high water table
- note growing conditions: soil wet or dry, bare, paved or mulched, competition from turf or weeds or dense vegetation.
- check for soil compaction, fills and grade change.
- consider how tree was planted: below grade, limited soil volume, root barrier, girdling root? etc.
- review horticultural practices – pruning history, fertilization, irrigation, cultivation herbicides, etc.
- consider soil contamination, reclaimed water, road salts, ocean spray, herbicides, excess fertilization, etc.
- check condition of root-flare
- check for recent or past site disturbance or injury.
- is surrounding vegetation strongly competitive?

***Common nutrient considerations:**

- N is **moderately** low in most soils.
- Most trees grow reasonably well and are green despite moderately low N.
- Nitrogen deficiencies are common in sandy soils low in organic content.
- Trees adjust growth to compensate for low N (less shoot growth/more root growth).
- High levels of N will not improve health.
- Most soils contain adequate levels of P and K.
- Nutrient deficiencies occur in strongly acid or alkaline soils Ca is low
- Boron toxicity is a problem in some areas.
- Serpentine soil high in magnesium are affect calcium uptake, limiting the growth of most plants.

Refer to available resources to check on common pests problems

**Diagnosing plant disorders**

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Diagnosis

Outbreaks of primary pests, those that can successfully attack healthy trees, are typically associated with host nutritional quality, spring growth, environmental conditions favorable to their development, or scarcity of natural enemies. Such pests need to be evaluated for their potential to affect tree health or appearance and managed accordingly. The presence, however, of secondary pests typically indicate a health-related issue, usually stemming from drought, soil aeration deficits, shade, advancing age, root loss, etc. Such disorders, often characterized by abnormal growth and appearance, are best determined by assessing symptoms (expression of damage to the tree), signs (evidence of the cause) and patterns of symptoms or occurrence. Each of these provides clues that can be useful in making a diagnosis. The following sequence of investigative steps may help in diagnosing a tree health problem.

1. *Identify the species*. Note what species are affected and whether some individuals are less affected than others. Check the condition of adjacent trees. Consider species characteristics, environmental tolerances, pest susceptibility, etc.
2. *Locate the damage*. Determine the part of the tree that is affected, e.g., leaves, twig, branches, trunk or entire tree.
3. *Look for patterns of occurrence*. Note if the symptoms are scattered or spread uniformly throughout the entire crown; is the damage limited to the lower or upper part of the crown, or to one side? Is the problem more severe in some areas than others, and are there differences between these areas? Are the problems limited to a particular environmental zone or related to a particular cultural activity? Did symptoms appear suddenly, and are they increasing or decreasing?
4. *Look for the presence of pests:* bacteria, fungi, insects, other invertebrate, mistletoe, etc. Try to determine whether the organisms found are the primary cause of the problem or just secondary to it. For example, pests will frequently infest trees that are weakened by drought or soil aeration deficits
5. *Assess environmental factors and site conditions*: Environmental conditions unfavorable to trees cause stress, leading to increased susceptibility to pests that attack stress-weakened trees, or environmental factors that favor the development of a pest.
7. *Assess health and condition*: health, vigor, age
8. *Consider past disturbances*: pruning history, current tree care practices,
9. *Consider obvious causes*. These include damage by animals, frost, drought, site disturbance, soil aeration deficits, fire, recent construction, etc.

**Management**

Integrated pest management (IPM) is a comprehensive and effective strategy for managing pests. Early detection of symptoms of stress-related problems is critical to minimizing pest injury. A management plan addressing appropriate horticultural practices to maintain favorable and stable growing conditions should be developed. In this manner, plant health and natural pest resistance can be enhanced or maintained, minimizing serious pest problems and greatly reducing the need for pesticides.

Integrated pest management (IPM) is a comprehensive and effective strategy for managing insect pests and disease-causing pathogens. It is a decision-making process that anticipates problems and prevents or minimizes damage by combining a number of different strategies to achieve long-term solutions to pest problems. This approach is based on the use of a combination of management options: chemical The most effective, long-term, and least toxic methods are emphasized. The following controls can be used:

- Biological: Encouraging natural control agents, reducing vegetative competition when planting seedlings or acorns; protecting seedlings from grazing or herbivory.
- Cultural: Proper planting techniques, mulching, judicious irrigation and pruning, use of resistant species, careful species selection and appropriate seed source.
- Mechanical: Eradicative pruning, hand-picking, hosing off, silica dusts.
- Physical: manipulation of environmental conditions, or mitigation of unfavorable environmental conditions, such as by loosening compacted soil, exposing the root collar and large lateral roots affected by oak root disease to drying, improving soil structure, providing drainage, removing fill soil, and mulching to moderate soil temperature, increasing exposure to sunlight, etc.
- *Chemical:* Applying conventional pesticides as well as oils, soaps, growth regulators, and biologicals, including competitive and antagonistic microorganisms for disease pathogens.

The objective of IPM is to maintain pest populations or disease damage below an unacceptable injury level. IPM relies on:

- regular monitoring to determine when pest populations or damage threaten to cause unacceptable injury
- early detection of symptoms
- identifying the pest(s) involved and/or environmental factors that may be contributing to the problem
- understanding pest biology
- modifying horticultural practices to promote plant health
- avoiding site disturbance and managing for environmental stability
- selecting and applying chemicals in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment
- proper timing and rate of chemical applications when required

## ENVIRONMENTAL FACTORS CAUSING STRESS

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All trees are periodically subjected to a variety of unfavorable growing conditions that can cause stress. Stress is a potentially injurious, reversible condition, resulting from a disruption of life-processes. Low to moderate stress slows growth and alters patterns of growth (shoot growth v. root growth), and typically increases carbohydrate storage and production of defensive compounds. This response has evolved to enable plants to adapt to changing conditions. Severe stress or prolonged moderate stress is non-reversible and causes injury, growth loss, decline, dieback or death. Trees weakened by stress are more susceptible to secondary pest problems, e.g., canker diseases, root diseases, bark beetles, borers. The effects of stress and injury are cumulative. Health and vitality decline with each stressful event or injury, further increasing susceptibility to unfavorable conditions or pest invasion. Stress-weakened trees respond more slowly to pathogen invasion, and a delayed wound response limits compartmentalization and reaction to invasion by canker-causing pathogens and wood decaying fungi. Susceptibility to insect and disease pests is the result of genetic attributes, environmental conditions, tree health, age, horticultural practices, stage of development, and pest virulence or aggressiveness.

Adverse environmental conditions such as drought, mineral imbalances, shade, air pollution, frost, soil aeration deficits, restricted rooting space or biotic stresses like defoliation/excess pruning, root loss, competition, advancing age, pest attack, etc., impair health by inhibiting life-sustaining processes. The intensity and duration of stress, condition and age of the plant and stage of development determine the impact on tree health. Stress can result from a severe episode of frost, drought, etc. or from chronic exposure to soil aeration deficits, mineral imbalances, air pollution, etc. Furthermore, environmental factors are constantly fluctuating and interacting.

The initial response to stress is slowed growth and increased carbohydrate partitioning to the roots. If the stress becomes acute or is chronic, growth, both primary (shoot elongation) and secondary (radial) may be severely retarded. This is followed by a reduction in carbohydrate (starch) reserves and an elevated concentration of sugar in the roots, as starch is converted for mobilization. This can increase susceptibility to certain pests (Harris 2004, Herms 1992), Dunn et al. 1990). Susceptibility to secondary pests like Armillaria root disease, carpenterworms, borers, bark beetles, canker diseases, etc., increases with increasing stress. Most serious pests are secondary to drought stress, construction-related impacts and poor horticultural care (Leland and Eads, 1965).

Trees produce callus tissue (wound periderm), which isolates the wound and inhibits spread of colonizing pathogens and reestablishes cambial continuity (Bostock and Stermer 1989, Mullick 1977). Rapid callus (woundwood) formation, essential for isolation of pathogens and compartmentalization, is a critical process. Neely (1983) reports that rapid callus formation is associated with vigorous cambial activity and trunk growth. According to Herms (1991), callus growth is sensitive to stress. Both drought and defoliation retard callus formation and increase susceptibility to woodborers and canker disease (Dunn, et al. 1990, Wargo 1987, Herms 1991).

### Mineral imbalances

Plants need a balance of water, minerals and carbohydrate reserves. Availability of minerals varies widely in both natural ecosystems and the landscape. So, mineral imbalances can present problem. Boron toxicities exist in some parts of the state and serpentine soils, which are deficient in calcium, can be found in other areas. In California, mineral deficiencies, particularly nitrogen, phosphorus and potassium are fairly rare. Optimal levels of nitrogen, though, seldom exist in soils because nitrogen is increasingly bound in woody biomass. It also leaches from the soil in the soil-water and is quickly converted back to the gaseous state. Despite continual loss of nitrogen to leaching, volatilization, and denitrification by soil organisms, soil nitrogen content, nevertheless, remains relatively constant due to natural deposition of nitrogen from the atmosphere, release of minerals bound in organic matter and that fixed by soil bacteria. Levels may vary somewhat on a seasonal basis.

Nitrogen provides the most universal response to plant growth because it is the most limiting nutrient in the soil. However, this is not to say that trees growing where nitrogen availability limits growth are unhealthy. Although nutrient deficiencies can slow growth, photosynthesis remains largely unaffected until nutrient deficiencies become severe. Trees compensate for imbalances in the availability of resources by shifting resources from foliar (shoot) growth to root growth. By slowing shoot growth, the root system is able to expand to exploit a larger volume of soil. This serves to balance nutrient supply and demand. Thus, trees growing in nutrient-poor sites typically have small crowns and expansive root systems. They are adapted to relatively low levels of nitrogen.

Trees use other strategies to improve their nutritional status, for example when exposed to nutrient deficiencies, plants roots typically increase their potential to absorb minerals (Harrison and Helliwell 1997). Glass 1983, demonstrated that nitrogen-deficient plants exhibit a high capacity to absorb available forms of nitrogen. In addition, potassium deficient plants have a high capacity to absorb potassium. Furthermore, plant roots are more likely to be colonized by mycorrhizal fungi when nutrient availability is limiting (Chapin et al. 1987). Mycorrhizal fungi are known to greatly enhance the uptake of certain minerals, including nitrogen. Another mechanism for trees to maintain growth in the face of limited supplies is to remove nitrogen from older foliage to growing meristems.

The fact that most plants respond to the addition of nitrogen is often used as justification for regular fertilization. It is wrongly assumed that the increased growth often associated with nitrogen fertilization is an indicator of improved health and vitality. Fertilization has long been promoted as a mean to enhance insect or disease resistance in landscape trees, but there is little evidence to support this claim. Most studies show that increased nitrogen availability in plant tissue in response to fertilization increases susceptibility to sap-feeding insects, leaf-feeding insects, root and canker diseases, certain leaf diseases, and browsing mammals (Yarwood 1959, Herms and Mattson 1992, Graham 1989). By improving nutritional quality of the plant, and by suppressing concentrations of defensive compounds, fertilization increases susceptibility to many pests. In favorable environments where water and minerals are not limiting, growth generally takes priority while carbohydrate storage and defense typically decline. Therefore, rapidly growing plants may actually be more susceptible to many pests. Trees growing in a nitrogen-limited environment grow more slowly, yet, typically have higher carbohydrate reserves and allocate more of it for defense than trees where there are no limitations.

Photosynthesis is dependent on leaf nitrogen content. Low concentrations of nitrogen reduce the rate of photosynthesis and availability of carbohydrate. Nitrogen stress causes a decline in stomatal conductance which causes a decline in photosynthesis and a slowing of growth. The more limiting the nutrient stress, the slower the growth. Life-sustaining processes are affected when nitrogen deficiency is severe. Except for very sandy soils and highly leached soils, nitrogen deficiencies are rare in natural and urban environments.

**Drought**

Water availability, primarily from rainfall, irrigation or a high water table is among the most critical environmental factor affecting tree establishment, growth, health and longevity. Prolonged or severe drought reduces growth, photosynthesis, and water-content of tissues, increasing susceptibility to secondary pests.

Water loss in plants is a natural and essential function. Most water is lost through the stomates in the leaves and the lenticels in the bark. When water is lost faster than it can be replaced by the roots, water deficit occurs and tree growth and health suffer. Excess transpiration typically occurs when temperatures are high, humidity is low, windy conditions persist, roots are damaged or soil moisture is too low or too high. The stomates close when available soil water is depleted, restricting water loss as well as photosynthesis. Respiration, nonetheless, continues, leading to potentially to carbohydrate depletion. Unless soil moisture improves, leaf wilt, leaf scorch, premature defoliation, branch dieback and death may result (Kozlowski et al. 1991). Heat, wind, humidity, light, leaf structure and leaf surface area influence water loss from plants.

Droughty conditions develop periodically over large areas, or prevail on sites where soil moisture is restricted by soil compaction, altered drainage patterns, fills, shallow, sandy or rocky soils, or certain topographic features such as ridge tops and south-facing slopes. Trees on such sites typically grow exceedingly slowly or are subjected to attack by secondary pests such as bark beetles, borers, canker diseases and root diseases.

Symptoms of water stress depend on the duration and severity of the drought. Typically, the younger leaves, depending on species, may wilt, shrivel, drupe, turn brown or drop prematurely. With increasing drought, older leaves are affected. Leaves under moderate drought stress may yellow or develop marginal leaf scorch. Symptoms first appear in the top and outer foliage and progress downward from the top and inward.

Water moves into the roots (across a semi-permeable membrane) via osmosis, that is—water moves from an area of high water potential (low salt concentration), typically found in the soil, to one of lower water potential (higher salt concentration), typically found in plant roots. High levels of salts in the soil restrict the uptake of water. Trees must accumulate salts or dissolved ions in their roots to increase the osmotic potential. This requires the expenditure of energy to do so.

Drought can have a profound affect on the growth and physiology of plants. For example, as water evaporates from the soil or is absorbed by plants, the concentration of salts in the remaining soil water increases. When the concentration of salts outside the roots exceed that within, which is likely to occur when there is a buildup of salts, water flows out, rather than into the roots. This condition is referred to as reverse osmosis. As this happens, the cell membrane shrinks from the cell wall and may eventually lead to death of the cell. Tree roots may be suberized (water-proofed) to limit water loss from the roots back into the soil. Nonetheless, drought can physically damage or kill tree roots. Non-woody, absorbing roots, typically located in the upper foot of soil, are most affected. Without functioning absorbing roots to provide water to the foliage, water deficit develops. In addition, there are other metabolic changes mediated by hormones, such as stomatal conductance, root water conductance, osmotic adjustment, restricted growth, leaf-shedding, etc. (Chapin 1991)

During droughty conditions the soil water is gradually depleted by root absorption and loss from the soil surface (evapotranspiration). As the available water is exhausted, the remaining water, which is held tightly by the soil particles, becomes increasing more difficult for the roots to absorb. In addition, the soil shrinks as it dries, creating a gap between the soil water and absorbing roots. Water uptake is further disrupted by the loss of continuity in capillary columns, which increases resistance to water movement toward the roots (Kozlowski et al. 1991).

Stomates open and close in response to light, humidity and water availability. Transpiration and photosynthesis occurs as long as stomates remain open. As water evaporates from the leaf surface it creates a negative pressure that moves water upward from the roots. Conditions or injuries that interrupt the flow of water may cause wilting or even lead to branch dieback.

Trees resist excessive rates of water loss through stomatal regulation. Stomates can be controlled by growth regulators (hormones) transported from the roots during droughts. Abscisic acid, formed by the roots in reaction to soil water deficits, appears to initiate stomatal closure. Most trees response to drought by closing their stomates to restrict water loss. Depending on the severity of the soil water deficit, stomates may take days or weeks to open and function normally, following replenishment of the soil water. Severe droughts may also cause permanent damage to the stomates. Increase in abscisic acid production also inhibits bud and leaf development and leaf abscission (Kozlowski et al. 1991).

Stomatal closure, vital to restricting water loss and conserving soil moisture, has a downside. The main disadvantage is that photosynthesis ceases as carbon dioxide is prevented from entering the leaves. This can cause defoliation, dieback and ultimately tree death as stored energy is depleted. The remaining stored energy is used primarily to support the living cells. Less is allocated for defense. Initially, there may be an increase in the production of these compounds because growth is more sensitive to drought that photosynthesis, thus carbohydrate reserves buildup. However, as the severity of drought persists the amount of defensive chemicals decreases and plants become vulnerable to pests that attack stress-weakened trees.

Acute or prolonged drought may damage the photosynthetic ‘machinery’ of a plant, making recovery more difficult. Before a plant can resume normal growth and metabolism or replace damaged tissues, it must reestablish the photosynthetic machinery and normal functioning of the stomates. Because food reserves may be greatly depleted, recovery may be slow and affected trees may succumb to pest attack. The full impact of drought stress may not be evident for weeks, months or even years. Some trees may dieback while photosynthetic capacity recovers. The extent of damage is dependent upon the severity and duration of the drought.

The fact that many of trees in our oak woodlands are more than one hundred years old, demonstrates that oaks have evolved mechanisms to withstand the adverse impacts of periodic drought stress. Blue oaks (*Quercus douglasii*) are known to drop their leaves early to reduce water demand. This appears to be a mechanism to avoid the potentially disastrous consequences of dehydration (McCreary 2000). Despite resistance to drought stress, oaks can be killed by severe drought. A high mortality rate for valley oak, blue oak, and coast live oak was recorded during a six-year drought (1986-87 to 1991-92) in Central California (Tietje 2000). Trees on ridge tops and South-facing slopes were most affected.

**Defoliation**

Severe or complete defoliation affects photosynthesis, reducing water and mineral uptake, growth and resistance to secondary pests (Kulman 1971, Wargo 1981, Schoenweiss 1975). Trees respond to serious defoliation by reducing root growth and increasing shoot growth (Wareing 1968). Defoliation of less that 50 percent generally has little impact, as the remaining foliage is able to compensate to some degree (Wargo 1987).

Defoliation seldom causes serious damage to vigorous trees unless it occurs in concert with other stressful conditions such as drought. Healthy deciduous trees are relatively tolerant of defoliation because they usually contain large quantities of stored carbohydrates. Oaks can often survive several consecutive defoliations without dying, although they may suffer severe growth loss or dieback (Herms, Nielsen and Sydnor 1987). Swiecki (1990), however, reported some mortality in oaks following several consecutive years of defoliation due to the California oak worm. Timing of defoliation is also critical. Heavy defoliation in the early spring usually results in a second flush of leaves that consumes much of the tree’s stored energy reserves (Wargo 1987). Wargo et al. (1972) reported a significant reduction of starch content in defoliated oaks. Stored energy is typically at its lowest level following spring flush. Those trees defoliated later in the year are less impacted because they have time to store carbohydrates. Vigor of affected trees prior to defoliation is also important (Kozlowski 1969). Wargo (1987) found that drought greatly amplified the effects of defoliation. Trees previously stressed by weather conditions or insect

/disease problems will have a harder time maintaining their health. Trees subjected to drought following defoliation may decline or succumb to secondary pest attack.

Serious mortality in blue oaks was reported in the hills above Stanford Campus in 1986. The trees were stressed by several years of drought and then seriously defoliated by several leaf diseases during the extremely wet spring of 1985. The oaks impacted by the long-term effects of drought were severely stressed by the defoliation and probably succumbed to root diseases. Severe anthracnose infections caused widespread defoliation of oaks following an unseasonably wet spring in 1993 in parts of Northern California. The leaves were succulent, the temperature was warm and there was rainfall – ideal conditions for anthracnose. No increase in mortality was reported, though (Owen, 1994).

Mortality in forest trees is often associated with previous insect or disease defoliation, for example, spruce bud worm, Douglas-fir tussock moth, gypsy moth, etc. The effects of defoliation vary with tree species, age, environmental conditions and presence of secondary pests.

**Soil aeration**

To remain healthy, tree roots require a constant supply of oxygen as well as water, minerals and sunlight. Oxygen is essential for aerobic root respiration (Kraemer and Kozlowski, 1979). This provides the energy needed to absorb water and minerals, transport materials, generate new growth and maintain natural defenses. During respiration, roots absorb oxygen from the soil, releasing carbon dioxide. Gaseous diffusion in the soil, therefore, is vital to prevent the accumulation of carbon dioxide and the depletion of oxygen.

Soil aeration is the exchange of air in the soil with that in the atmosphere. Oxygen diffuses from the atmosphere into the soil through the pore spaces between the larger soil particles and aggregates within the upper soil layers. Carbon dioxide produced by the roots and soil organisms during respiration, diffuses upward into the atmosphere. In well-drained soils there is usually adequate exchange of oxygen from the atmosphere to prevent depletion of oxygen levels in the soil. Aeration deficits and harmful concentrations of carbon dioxide can accumulate when gaseous diffusion is restricted. Factors that can restrict soil aeration include excess soil moisture, soil compaction, fill-soil, surface barriers, etc. Low oxygen levels can also predispose roots to root disease (Costello, et al. 1991, Drew and Lynch 1980).

Soil aeration is determined by both soil texture and soil structure. In general, finer soils, due to a higher proportion of smaller soil particles and small pore spaces, tend to drain poorly and hold less oxygen than coarser, sandy soils or well-structured soils. Water retained in the small pores displaces oxygen, inhibiting gaseous diffusion. Soil structure, the aggregation of soil particles into larger *aggregates*, however, can greatly increase the proportion of large pore spaces.

Diffusion is rapid in soils when there are numerous large pore spaces These ‘macropores’ allow air and water to move freely within the soil. There is little movement of oxygen in the smaller pore spaces (microspores) commonly found in compacted soils, and in heavy clays where the soil particles are exceedingly small. The reason is that there are few, large pores in such soils and the small pores are largely filled with. The size, number, and distribution of pores influence how air and water move through the soil. Aeration can also be a problem in waterlogged soil because much of the larger pore space is filled with water. When soil aeration is poor, anaerobic soil conditions develop, and plant growth is limited.

**Soil compaction**

Soil compaction, resulting from heavy foot traffic, livestock, construction-related activities, vehicle parking, etc., eliminates much of the soil’s natural porosity, which allows for water movement (infiltration and drainage), soil moisture retention, gaseous diffusion and root penetration. Soil aggregates, which provide much of the macropore space in soil, are broken down, allowing the individual soil particles to be compress together. The result is that compacted soil is less favorable for root growth– it is less permeable, holds little available water, contains little oxygen, and is more resistant to root penetration. Soil is more readily compacted when the soil is wet and when the surface organic layer (natural mulching) is removed.

Most tree roots cannot function in soils where gaseous diffusion and drainage are restricted. The accumulation of high levels of carbon dioxide, produced by the roots during respiration, can also impair root function. Furthermore, inadequate soil oxygen favors the development of root Phytophthora root disease. It also inhibits mycorrhizal fungi (beneficial fungi) that enhance water and nutrient uptake and resist root pathogens.

**Excess soil moisture**

Flooding, impeded drainage and over-watering are detrimental to most trees, because the excess water displaces oxygen in the soil, leading to anaerobic condition. The symptoms of which include wilting, yellowing, defoliation, marginal browning and leaf death. Other impacts include reduced photosynthesis, energy depletion, dieback and decline. Many aerobic soil organisms, which aid in nitrogen fixation and organic matter decomposition, as well as mycorrhizae, are replaced by anaerobic bacteria. The latter cause the volatilization of nitrogen and produce toxic compounds. Additionally, excess soil water predisposes roots to certain soil-borne pathogens. These pathogens are attracted by root exudates (sugars and amino acids,) and they take advantage of the plant's stress-weakened defenses. Canker diseases are also more common on flood-stressed trees.

Flooding occurs periodically in low-lying areas, floodplains, along lake shorelines, riverbanks and in meadows in the spring. Flooding during the growing season typically is more harmful to trees than flooding during the dormant season. And, the longer trees are exposed to flooding, the greater the potential for injury. Short periods of flooding during the growing season, can be tolerated by most trees, but if flooding is recurrent or uninterrupted and the soils remain saturated, serious damage to oaks may occur. Specifically, trees are most susceptible to flooding in late spring just after the first flush of growth. Duration is also a critical determinant in injury. The longer trees are exposed to flooding, the greater the potential for injury. Most oaks can withstand some flooding, for example, valley oaks in some locations are often inundated during the winter for weeks at a time. Healthy, mature, trees appear more tolerant of flooding than over-mature trees and those already under stress. Trees that survive flooding often have a reduced root surface area, as non-woody roots are more susceptible to injury. Thus, water and nutrient absorption may suffer following a flooding event. Once floodwaters recede, it may weeks for photosynthesis to return to normal. Flooding can also deposit sediments, which can reduce soil aeration.

**Fill soil**

The placement of fill soil around established trees has generally been viewed as having a negative impact on tree health. Fill is thought to act as a barrier to the diffusion of atmospheric oxygen into the root zone, causing aeration deficits that impairs root function. To prevent or minimize aeration deficits, aeration systems have been prescribed for installation under the fill to aerate the root zone. However, recent studies and field observations indicate that the impacts and management of fill soil around trees should be revaluated. Research indicates that soil aeration deficits may not be responsible for causing poor tree performance. Specifically, altered water relations, soil compaction and mechanical injury to roots were noted as possibly having an equal or greater effect on tree health than changes in soil aeration.. Although Yelonsky (1963) found that forest trees were severely injured by fill soil spread over their root zones, more recent studies (Day et al. 1995, MacDonald et al. 2004, Smith et al. 1995) have found little or no effect of fill on tree health. Site condition and species factors may account for this discrepancy. Nevertheless, it is fairly evident from field observations and research that root injury often does not occur following fill installation. Townsen et al. (2003) reported that "fill soil reduced oxygen and increased carbon dioxide slightly, but not nearly enough to produce concentrations unfavorable to tree growth and development." Poor growth following the installation of fill is more likely due to water deficits rather than aeration deficits. Most of the authors concluded that restricted water percolation through the fill soil to the base soil is thought to be cause of injury resulting from fill soil.

It is likely that multiple factors contribute to tree injury following the addition of fill soil: water deficit, soil compaction, aeration deficit and mechanical roots injury. The effect of each of these factors is influenced by species tolerance, site conditions (fill texture and base-soil factors, slope) and methods of fill installation (Costello and Day 2004). Although aeration systems have not been shown to improve aeration status in the root zone (Day et al. 1995, MacDonald et al. 2004, Smith et al. 1995), tree wells are still considered useful by most practitioners. Management plans for the placement of should address all potential factors that may play a role during the pre-fill, fill installation, and post-fill phases. By developing a careful and complete plan, it is likely that the potential for tree injury can be minimized (Costello and Day 2004).

Grade fills within the root protection zones of trees should use dry, coarse or permeable fill placed in a manner that avoids serious soil compaction. Building regulation typically require that the fill used for a load-bearing surfaces, such as structures or pavement must be engineered–that is, placed in lifts 6 to 8-inch deep layers which are then compacted to 95 percent (proctor scale). This type of soil compaction does greatly impact soil conditions within the compacted layer and below. It's best to consider other alternatives. For more information regarding preserving trees during development see Chapter?

**Shade**

The importance of light for photosynthesis is well known. The amount of light available to developing seedlings and young trees has a major impact on their rate of growth and growth form. Heavy shade greatly reduces the rate of photosynthesis and carbohydrate production. This in turn affects rate of growth. Trees growing in dense shade are typically spindly, with few lateral branches and a low live crown ration. Few trees grow well in dense shade—most die or are suppressed. Oaks are intermediate in their tolerance to shade. Shade also affects growth habit as trees and branches grow away from the vertical toward the highest levels of sunlight. Unless oaks receive some sunlight they will invariably languish and die. Many oak woodlands stands are characterized as 'closed–canopy' stands composed predominantly of several species of oaks and other broadleaf evergreens and occasionally conifer species. Species composition in such forests is quite variable due to differences in climate, elevation, soils, water availability and topography—slope and aspect. The crowns of such stands overlap, forming a mosaic if you will, so little sun light reaches the ground. Stands can be very dense and the trees relatively small in diameter. Some trees in older stands can grow quite large. The largest trees growing above the rest, receiving sunlight from above and from the sides are known as dominant trees. They are the generally the healthiest trees in the stand. Smaller trees receiving sunlight from the primarily from above and some from the sides are the codominant tree, these tree too are relatively healthy and most likely to become dominant if the dominate trees fall or are removed. Those receiving only the light from above are smaller yet, and are referred to as intermediates. They do not receive enough sunlight to be healthy. They are often killed during droughts. Trees beneath the canopy, receiving no direct light are suppressed and are typically small and spindly and with sparse foliage. The latter usually languish for a number of years before dying, unless taller, neighboring trees are removed or fall, opening up the canopy.

**Temperature extremes**

High temperatures have a detrimental effect on tree leaves and roots. Leaves normally dissipate heat by transpiring water. Heat is lost as water evaporates from the leaf surface through the stomata. The optimum temperatures range for most trees is about 70°F to 85°F. Injury typically occurs when the air temperature reaches about 115°F. The duration of high temperatures, the highest temperature reached, tissue water content, tissue age, tree response and species tolerance determine the extent of damage. Heat injury includes leaf scorch, leaf death, shoot death, sunburned bark and retarded growth, increased respiration and energy depletion.

Trees with adequate soil moisture can readily dissipate heat. High temperatures, though, decrease humidity, causing rapid water loss, which may result in stomatal closure. Thus, transpirational cooling is limited and increasing leaf temperatures may cause injury.

In urban areas, asphalt and concrete absorb and reflect heat, increasing the air temperature around trees. Trees along roads and in parking lots are often subjected to near lethal temperatures from the reflected or radiated heat. Temperatures in urban sites can be as much as 10 degrees warmer than in rural sites. Buildings reflect heat onto trees, especially along southern and western walls. In addition, buildings and paved areas continue to radiate heat even after sunset.

The soil surface also absorbs heat, which can affect roots. In full sunlight, bare soils can reach 150°F. Optimum root growth occurs when soil temperatures are between 60° F and 80° F. When soil temperatures exceed 95° F., root function begins to decrease significantly. The effects of high soil temperature can be mitigated by applying a 2 to 4-inch layer of wood-chip mulch to reduce soil temperature and help conserve soil moisture.

Irrigation during unusually hot periods can help minimize high temperature damage by ensuring adequate soil moisture. Water deeply from about the midway point from the trunk to the dripline (periphery of foliage) and at least 10 feet beyond (see section on oak irrigation).

**Low temperature** is seldom a serious problem for native oaks unless they were propagated from acorns collected from lower elevation and planted beyond their range of tolerance.

**Air pollution**

The adverse effects of air pollution on trees have been well documented**.** The effect though on urban trees is largely unknown. Major phytotoxic air pollutants include ozone, peroxy acetyl nitrate (PAN) and sulfur dioxide. Gaseous pollutants, such as ozone and sulfur dioxide, enter plants through the leaves and inhibit photosynthesis. Acute damage levels can be high enough to cause tissue damage, decline and susceptibility to secondary pests. Chronic damage occurs when small amounts of toxic gases enter leaves, inhibiting leaf functions rather than injuring tissue.

Whether or not an air pollutant causes acute or chronic damage depends upon tree species. Individual trees within a species often display varying degrees of tolerance to the same pollutant. Air currents influence pollutant concentration, chemical reactions and the duration of tree exposure to pollutants. Geographic features that trap air or weather conditions that cause air inversions exacerbate air pollution. Temperature also has affects a pollutant’s chemical reaction rate. When the temperature is high, more photochemical oxidants are produced. These oxidants cause more severe damage during sunny, hot weather and less damage during cool, cloudy weather. Atmospheric moisture causes pollutants to become solutions, increasing their toxic potential. Elevated levels of ozone cause stress, mortality and growth reductions in the hardwood and coniferous forests in the mountains surrounding the Los Angeles Basin in California, and those in the central and southern Sierra Nevada.

**The impacts of stress: dieback and decline**

Every tree reaches a point where the need for water, minerals or sunlight cannot be met, and dieback is initiated. This is a survival strategy allowing trees to adjust to adverse conditions. In essence, trees can shed some tissue in order to support the remainder (Houston 1985). When stress abates, the dieback process ceases and the tree recovers. When the stress is prolonged or severe the dieback mechanism may not be enough and the tree may succumb to secondary pests. Stress alone can also cause mortality by inhibiting critical physiological processes.

Dieback and decline describes the progressive death of buds, shoots and branches, both inward and downward, culminating in the death of the tree. Leaves of declining trees are often small, sparse and off color. Sometimes the leaves drop prematurely. Dense sprouting (epicormic shoots) growing on the trunk and larger branches usually following defoliation or branch dieback is an indication of severe stress. These sprouts play an important role in the survival of the tree by provided needed carbohydrate. They should be left undisturbed for several years and then carefully managed thereafter. Susceptibility to secondary pests, e.g., cankers, borers, bark beetles, root disease, etc. is also symptomatic.

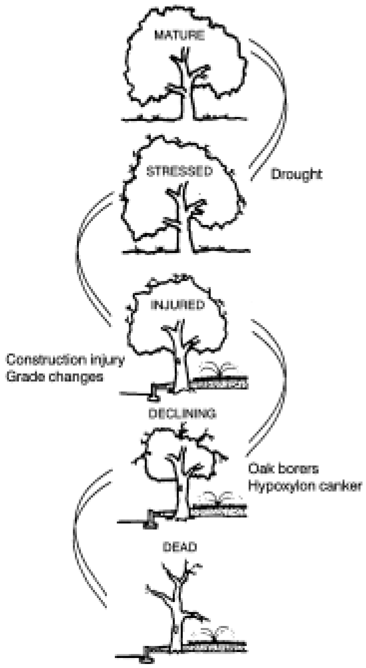
Dieback and declines are complex disorders involving multiple factors. Dieback is usually the result of a succession of stressful conditions or events, e.g., chronic or acute drought stress, drought exacerbated by heat, severe nutrient deficiency, defoliation, root injuries, soil aeration deficits, air pollution, loss of health due to advanced aging, and nearly always–pest attack or disease invasion. Periodic decline of oaks, followed by noticeable mortality over large areas throughout California has been recorded (Swiecki and Bernhardt 1990). Many declines of hardwood forests throughout the United States have been linked to drought or defoliation. Significant mortality was reported in several Central Coast counties following six-year of drought of 1987-1992 (Tietje et al. 1993). Wide spread oak mortality as seen like in recent years in northern and central coastal California due to *Phytophthora ramorum,* the sudden oak death pathogen, has not been reported in the past. This type of dramatic mortality is the result of an introduced pest rather than a dieback decline.

Recovery from decline, with the exception of Sudden oak death, depends on restoration of favorable growing conditions, tree age, vigor, presence or absence of secondary pests, aggressiveness of the pest(s) involved, location and the severity of tissue invasion. Often times, trees in decline are too weak to respond to favorable growing conditions and continue to decline, regardless to whatever is done.

Decline usually involves the development of symptoms beginning with dieback of buds, twigs and branches, progressing inward and downward, often culminating in the death of the of the tree. Leaves of declining trees are small, sparse, off color and progressively born on epicormic sprouts (water sprouts). Despite therapeutic intervention, most trees affected by decline eventually die, usually a result of secondary pests.

**How trees die**:
Oaks seldom die of old age. Many die as a result of structural or catastrophic failure. Injuries, broken branches, fire scars, dying branches, large pruning cuts, heading and flush cuts, etc., serve as entry points for decay-causing pathogens that progressively weaken the wood of roots, branches and trunk. Root, branch and trunk decay play a major role in failure and may contribute to decline. Site disturbance and environmental degradation are also responsible for the decline of many trees.

In most cases, a complex of interacting biotic agents and abiotic (environmental) factors are involved in tree decline and mortality (Sinclaire and Hudler 1988). Franklin, Shugart and Harmon (1987), proposed the term *mortality spiral* to describe the series of interrelated stressful events, disturbances and pest attack leading to decline and eventual death of trees. With each step, vigor decreases and susceptibility to lethal, secondary pests increase. In general, no single event, site disturbance or pest is sufficient to cause death. It is their cumulative effect that is important. Each stressful event reduces vigor, increasing susceptibility to secondary pests.




Health and vitality (plant performance) decline with age, as trees become larger, more complex, and less efficient. Susceptibility to pests, particularly stress-related organisms, progressively increases as trees age and their vitality declines. Secondary pests, particularly bark beetles, borers, canker-causing pathogen and root decay organisms are usually involved in tree mortality.