INCREASING CANOPY COVER IN ASPHALT AND OTHER HARD SURFACE TREATMENTS

Justin Morgenroth

2005

Abstract

It has generally been accepted that by planting trees in hard surface treatments such as asphalt, concrete, or interlocking brick their future growth and survival will be compromised. This is certainly the case at the Toronto District School Board (TDSB). This perception is based strongly on intuition rather than empirical study. While studies have reviewed specific physiological responses to single stresses such as drought, no studies have considered the effect of chronic compounding stresses on overall tree condition. Using the Neighbour*woods*© program, this study determined that associations between tree condition and surface treatment were only present in locations which experienced low intensities of use. Conversely, trees planted in intensely used areas such as school playgrounds were not affected by varying surface treatments. In other words, the overall conditions of trees planted in soft surface treatments such as mulch, bare soil, or turf were no better than those of trees planted in hard surface treatments. This likely resulted due to higher levels of stress inherent to high use locations. The implication of this result is that the TDSB can reassess their current planting practices by supporting the planting of trees in hard surface treatments for high use locations. This policy change is the first step to increasing canopy cover where it is most needed, in playgrounds which are predominately covered in asphalt.

Keywords: *urban forestry; surface treatment; rooting environment; Neighbourwoods*.

Acknowledgements

I would like to acknowledge my supervisor, Andy Kenney, for his insights and support. For the opportunity to work on this project, I thank Bruce Day and Adrina Ambrosii. Bruce's commitment to improving the management of the Toronto District School Board's tree cover, and his species identification skills were crucial to the establishment and success of the tree inventory. I thank Adrina for creating the framework for the inventory. Her organization and dedication have guaranteed the continued success of this project for years to come. The summer of 2005 would certainly not have been as productive, nor fun, had it not been for Sarah Lamon. She beat me to work every morning and made certain that my coffee breaks didn't last all day. We had an outstanding summer together and I would cherish any opportunity to work with her again.

The analysis and writing of this report could not have succeeded without the help of Jules Norghauer or Adam Martin. Jules dedicated countless hours to discussing data analysis techniques, while Adam's editing was crucial in shaping the final product.

A final round of thanks goes out to all my labmates, friends and family who supported me over the past 16 months. Notably, I would like to thank Lisa for her support, understanding and interest in what I study. But most of all, I would like to thank my parents, both of whom never stopped emphasizing that I should love what I do.

Table of Contents

List of Figures and Appendices

Introduction

The environment in which urban trees grow is fraught with challenges. Air pollution (Wen *et al.* 2004), relatively high temperatures (Lindsey & Bussak 1991), moisture availability (Whitlow *et al.* 1992) and mechanical damage (Schwets & Brown 2000) contribute to the stressful environment in which urban trees are expected to survive and perform ecological services, such as:

- decreasing air pollution through sequestration and emission reduction (Akbari 2002, Heckel 2004)
- decreasing water pollution, by minimizing storm-water runoff (Xiao *et al.* 1998)
- increasing urban wildlife habitat (Dunster 1998);

These benefits are compromised when trees are planted in harsh growing environments that have the potential to retard tree development, put the tree at risk of defects, and ultimately, result in premature mortality (Nowak *et al.* 1990). This consequence reduces the benefits provided to the community by the affected tree. A contributing factor to success, which is often overlooked, is a tree's surface treatment. To begin, as the interface between the atmosphere and the soil, it affects critical water and nutrient relations. Furthermore, the surface treatment protects the root system from mechanical damage. The Toronto District School Board (TDSB) recognizes the challenges faced by trees on its school grounds and is committed to increasing its understanding of a tree's surface treatment and its effect on tree condition. By qualifying this relationship, school grounds will profit from the aesthetic, ecological and safety benefits provided by healthy, vigourous trees.

The TDSB is the second largest land owner in the recently amalgamated City of Toronto. Its properties are located throughout the Greater Toronto Area (GTA), more specifically in the former municipalities of Etobicoke, York, East York, North York, Scarborough, and Toronto. In 1998, these municipalities amalgamated as the new City of Toronto. Serving a population of 2.4 million people, the TDSBs 30,000 staff members administer and educate 300,000 students, while maintaining approximately 600 schools and over 5,000 acres of property. Prior to amalgamation, each municipality's school board maintained their properties in a manner commensurate with current standards. Though there was communication between municipalities regarding best practices, no standards were exacted and thus school ground landscapes differed greatly from one school to the next. Of the six original school boards, only the former Toronto Public School Board (TPSB) subscribed to the concept that trees could be planted in hard surfaces including asphalt, concrete, and interlocking brick. The former TPSB pioneered tree planting techniques for hard surfaces that other school boards believed were inhospitable, and hence provided shade in high use locations such as school playgrounds, where it was most needed. Since amalgamation, strong efforts have been made to increase tree cover in playgrounds throughout the TDSB. Efforts have specifically been directed towards planting trees in hard surfaces as these areas have typically been devoid of tree cover.

Historically, trees have not been planted in hard surface treatments as it was widely believed that trees could not survive, let alone thrive when surrounded by asphalt, concrete or interlocking bricks. Impermeable surfaces reduce infiltration of water and nutrients to trees that are consistently under stress from a variety of climatic and site-specific conditions (Hodge & Boswell 1993; Cregg 1995; Cermak *et al.* 2000). Intuitively, trees in these surfaces should be at a distinct disadvantage in terms of their overall condition. These convictions are rational, but they have yet to be empirically proven. This study will undertake the assessment of the overall condition of trees based on a set of compounding stresses, in order to establish the relationship between tree condition and surface treatment. Gaining practical insight into the suitability of different surface treatments will enable accurate and successful selection and design of planting sites within the urban environment. Furthermore, different species possess innate physiological responses to stresses. As such, this study will examine species-specific correlations between surface treatments and overall tree condition.

The selection of planting location can affect water and nutrient relations, as well as, the incidence of mechanical damage. These factors influence the vigour and survival of trees and thus planting location must be considered carefully. By increasing our basic understanding of the relationship between a tree and the surface which surrounds it, this study will characterize the suitability of different surface treatments in which to plant trees. In addition to determining optimal surface treatments, this study will provide the TDSB with an index describing the suitability of species with respects to different surface treatments. The results will influence planting guidelines, potentially leading to a board-wide planting policy. The knowledge gained from this study will provide grounds teams with the information needed to plant trees effectively such that benefits are maximized.

In addition to trees' ecological benefits, they provide a variety of specific benefits for schoolyards, more specifically playgrounds. Playground shade is currently at the forefront of research associating childhood sun burns with the development of skin cancer in adulthood (Crane *et al.* 1993; Livingston *et al.* 2001; Horsley *et al.* 2002; Geller *et al.* 2003). A variety of sources have identified increasing canopy cover amongst the possible solutions for reducing the occurrence of potentially cancer causing sun burns in school playgrounds (Geller *et al.* 2003). In addition to providing shade, tree cover:

- reduces temperature through shade provision and evapotranspiration (Long-Sheng *et al.* 1993, McPherson 1994);
- provides shelter from frigid winter winds (Brown & Gillespie 1995);
- improves psychological well-being (Hernandez & Hidalgo 2005);
- provides an outdoor learning environment; and
- promotes recreation

These benefits can only be obtained if TDSB planting policy reflects the need for more trees in playgrounds, which are swathed with hard surfaces. Turf and bare soil are unable to withstand the intensity of use inherent in playgrounds, hence the need for hard surfaces. By determining the relative suitability of different surface treatments including asphalt, interlocking brick, turf, mulch, and soil this study will provide the TDSB with the necessary information to determine optimal planting locations and potentially increase canopy cover within high use locations, specifically playgrounds.

Current State of Knowledge

Assumptions and theoretical beliefs have historically guided decisions regarding suitable planting locations for trees in urban environments. Soft surfaces, whether vegetated (i.e. turf) or non-vegetated (i.e. soil, mulch) have typically been preferred to hard surfaces (i.e. asphalt, interlocking brick) as it has been presupposed that they offer a more hospitable surface treatment (Montague & Kjelgren 2004). In recent years, however, studies have taken an unbiased approach and determined the benefits and drawbacks of various surface treatments. The bulk of these studies have documented various physiological and morphological responses of a limited number of species to surface treatments including turf (Schwets & Brown 2000), organic mulch (Montague & Kjelgren 2004), asphalt (Montague & Kjelgren 2004), and soil (Schwets & Brown 2000).

Water Relations of Trees in Different Surface Treatments

These studies have focused on one or, at most, several stresses and their effects on the survival and vitality of trees. Their narrow focus, as well as their relatively small data sets account for their conflicting results. Some studies have observed that trees rooted in turf have higher water potentials than those surrounded by asphalt, thus implying that trees in asphalt are more susceptible to water stress than trees in turf (see Cregg 1995; Wagar & Franklin 1994). In contrast, Kjelgren and Montague (1998) and Close *et al.* (1996) suggest that water stress is greater for trees planted in turf than for those planted in asphalt. These inconsistencies may be artefacts of short temporal scales or the climate in which the studies were performed.

The effect of short temporal scales is an inability to control for seasonal or annual variations in rainfall. To explain the variation that they observed in water potential, Hodge and Boswell (1993) concluded that during times of low precipitation, moisture stress is greatest in turf due to strong competition. In contrast, during times of high precipitation moisture stress is greatest in hard surfaces due to surface runoff.

Climate, in particular atmospheric vapour pressure, is another possible explanation for contradictory results concerning water stress. A humid climate creates a low leaf-to-air vapour pressure gradient, while arid climates generate steep leaf-to-air vapour pressure gradients. Thus, water relations are climatically specific and temporally constrained. Current research has not adequately predicted tree water stress as a function of surface treatment for urban areas.

Growth Comparisons of Trees in Different Surface Treatments

Growth rates are a further example of the disparity found in the physiological examination of urban trees. Cregg (1995) found that trees in turf had higher photosynthetic rates and accordingly higher growth rates. This is contradictory to Hodge (1991) who discovered that trees in turf grew more slowly than trees in asphalt. The conflicting results found in growth and water relations studies suggest that there are interactions and external factors in place that determine the vitality of trees in their respective surface treatments. Accordingly, this study will consider interactions in order to gain a holistic understanding of trees in different surface treatments.

Survival of Trees in Different Surface Treatments

In their study of tree mortality, other researchers have considered these very interactions to determine the events responsible for premature mortality. Reasons for tree mortality are difficult to determine, as a combination of stresses or disturbances are often responsible. Chronic compounding stresses such as water and nutrient deficiencies will prove insurmountable and trees will succumb to premature mortality. Despite the difficulty in determining specific causes of death, it is certainly possible to determine mortality rates for different urban environments. For example, annual street tree mortality in Oakland, California is 19% and the rate was found to increase in cities with cooler climates (Nowak *et al.* 1990).

Beatty and Heckman (1981) in the United States and a similar study undertaken in Britain (Gilbertson & Bradshaw 1985) suggest that mortality rates may be a function of city size, with greater mortality occurring in larger cities. The latter two studies were consistent in that their findings suggested water and nutrient stress to be most strongly correlated with premature death, while vandalism was a strong secondary factor. These primary causes hinted towards the superiority of soft surfaces due to their permeability, but no conclusions were drawn. Though these studies illustrate the variability of tree survival in urban areas, they are inapplicable for the purposes of urban forest management as they do not distinguish between surface treatments. These studies are thus incapable of enabling accurate and effective site-selection for future planting.

The only study of the effects of surface treatment on tree survival was conducted by Schwets and Brown (2000). They concluded that there was no difference in survival rates between trees adjacent to asphalt and trees adjacent to turf-covered open areas. While the study provided a useful comparison, these conclusions were based on three sites, with as few as twenty trees. Small sample sizes can have difficulty controlling for variation in results due to phenotypic variation, micro-climate variation or other external factors.

Limitations of Current Research

Such studies (see Hodge & Boswell 1993; Cregg 1995; Schwets & Brown 2000) are important as they isolate particular response variables in an effort to further comprehend the physiological adaptations of trees in urban environments. The management implications are, however, limited by small data sets, contradictory results. Furthermore, by not distinguishing between different surface treatments, a significant factor is ignored. In contrast, this study recognizes that stresses do not affect trees independently, but instead, have compounding effects. Rather than focusing on responses to a specific stress, this study will assess the overall condition of urban trees, based on a set of criteria, to establish the relationship between tree condition and surface treatment.

The Effects of Surface Treatment on Physiology

Properties of different surface treatments such as porosity and thermal conductance can provide trees with advantages or disadvantages. Together, this suite of properties limits the interactions that occur at the soil/atmosphere boundary and defines the environmental attributes that affect roots and hence, tree survival and condition. Such attributes include infiltration of water and nutrients, soil compaction, soil temperature, leaf temperature, and oxygen diffusion into the soil. Due to the varying properties of different surface treatments, it is logical to assume that they will affect environmental attributes and consequently tree condition.

In order to understand the consequences of each surface treatment, an examination of the literature was necessary. The following is a review of the effects of prevalent hard and soft surfaces on tree physiology.

Asphalt

Asphalt is the most common hard surface in urban environments. Its structural integrity is necessary for a variety of uses including roads, boulevards, parking lots, and playgrounds. Its smothering appearance dissuades urban foresters from planting trees in it if an alternative location is available. Due to its impervious nature, asphalt impedes water, nutrients and oxygen from entering the soil below it where tree roots reside. Hodge and Boswell (1993) found that levels of foliar nitrogen and phosphorous in the leaves of trees planted in asphalt were lower than published deficiency thresholds, thereby suggesting that concentrations of nutrients in the soil below asphalt were lacking.

Interestingly, the water relations of trees planted in an asphalt surface treatment are not fully understood. It is well established that the water potential of trees surrounded by asphalt are often lower than for those planted in turf, mulch, or soil, resulting in water stressed conditions (Cregg 1995). What remains uncertain is whether trees planted in asphalt surface treatments conserve water more stringently, and furthermore, whether the water potential of trees in asphalt is low enough to be damaging.

Kjelgren and Montague (1998) argue that the long-wave thermal radiation emitted from asphalt increases leaf temperature and leaf-to-air vapour pressure deficit, which acts to close the stomata and thus reduce water loss. Conversely, Zajicek and Heilman (1991) have documented that water loss does increase due to elevated leaf temperatures and the associated increase in transpiration. The likely difference in their findings is the atmospheric moisture content of their study sites, the first of which was arid, while the other was a humid site. Stomata will remain open longer in humid environments, as the water potential gradient is less steep than in an arid environment. Thus, during Toronto's humid summers, it is likely that trees surrounded by asphalt would suffer water loss.

The danger of water loss is a decrease in cell turgor. This affects trees in two different ways, the first being that stomatal guard cells lose turgor and hence stomata close. This limits photosynthetic activity (Cregg 1995). Secondly, cell turgor is required for cell growth (Proseus *et al.* 2000). Ultimately, tree growth is hindered by lack of photosynthesis and cell growth.

Belowground temperatures are also affected by asphalt, thereby affecting tree roots. In the absence of evaporative cooling, asphalt temperatures can become 20-25 ˚C higher than turf during the afternoon hours (Kjelgren & Montague 1998). The thermal radiation is transmitted into the rhizosphere generating soil temperatures high enough to damage tree roots (Celestian & Martin 2004). Finally, asphalt's impervious nature is responsible for a reduced oxygen diffusion rate, leading to reduced root growth due to hypoxia (Cermak *et al.* 2000).

Thus, the results of numerous studies would suggest that asphalt is an inferior surface treatment, which places the tree under water and nutrient stress, ultimately leading to poor growth. However, studies examining the effect of asphalt on overall tree condition are lacking.

Interlocking Brick

Interlocking brick is used primarily for aesthetic purposes. It is similar to asphalt in that it is nearly 100% impermeable. Thus trees surrounded by this surface treatment are subjected to minimal nutrient and water input, as well as poor oxygen diffusion rates. Other porous pavers address these issues by modifying the shape, size and design of individual pavers. The desired effect is achieved by integrating holes throughout the pavers, while maintaining their structural integrity (Figure 1). They vary in porosity and presumably, their effect on the surface treatment of trees. Safety is paramount in urban environment and unfortunately pavers often heave due to root growth near the surface of the soil. This liability creates a tripping hazard. Smaller pavers like interlocking brick are superior to larger ones like quads in this respect. The importance of these pavers is that they minimize the impediment of water and nutrient flow into the soil while providing the structural integrity necessary in portions of the urban landscape.

Contrasting Bricks and Porous Pavers

a) **b)** **c)**

Figure 1. Pavers offer varying degrees of porosity: a) interlocking brick (0%); b) turfstone (~27%); c) ecostone (10%).

Turf

In a turf surface treatment, grass and tree roots share the same soil horizon. This leads to competition, particularly as tree root density increases in the top 7.5 centimetres of soil to maximize access to infiltrating water and nutrients (Watson 1988). The result is water (Close *et al.* 1996) and nutrient (Davies 1985) stress which have been strongly associated with premature mortality (Gilbertson & Bradshaw 1985). Young trees are especially susceptible to these deficient conditions (Davies 1985), thereby resulting in a disproportionate mortality rate for newly planted trees (Nowak *et al.* 1990).

Interestingly, turf is not always correlated with poor water and nutrient relations. As previously noted, Hodge and Boswell (1993) have suggested that tree root water stress was severe only during seasons with markedly low precipitation. They also discovered that nitrogen, phosphorous, and potassium were found in high abundances in the leaves of their subject trees and concluded that tree roots absorb fertilizer applied to turf. Thus, macro-nutrient deficiencies may only affect trees in unfertilized turf.

Despite its competitive nature, turf can be an advantageous surface treatment in terms of temperature relations. To begin, a cooler micro-climate can be achieved through evapotranspirational cooling (Long-Sheng *et al.* 1993). Also, the flux of long-wave thermal radiation emitted by turf is minimal relative to other urban surfaces, resulting in afternoon surface temperatures of 20-25 ˚C lower than asphalt (Kjelgren & Montague 1998). As such, the contribution of turf-covered surface temperature to increased leaf temperatures is minimal (Montague & Kjelgren 2004). If all other factors are held constant, comparatively low leaf temperatures allow for greater stomatal conductance and later daily stomatal closure, thereby augmenting the leaf's photosynthetic potential (Montague & Kjelgren 2004).

Soil

Physical soil properties will typically dictate the suitability of bare soil as a surface treatment. Soil texture will influence water and nutrient infiltration, water holding capacity, and root growth impedance (Kozlowski 1999). Soil volume is ideally represented by 50% soil particles (45% mineral 5% organic), 25% air, and 25% water. Should soil be high in clay content, pore size decreases and hence air decreases, displaced by water molecules. The result is a reduction in the percent air-filled pore space and conditions can become anoxic (Watson & Kupkowski 1991). Conversely, if soil content is dominated by sand, pore size increases, resulting in decreased water holding capacity. The available water content (AWC) of a soil quantifies the moisture available to tree roots. In ideal conditions, the AWC of a soil rarely restricts water-limited physiological processes such as photosynthesis.

While infiltration of water into bare soil is relatively unimpeded, soil compaction, which is rarely unavoidable in urban environments, can severely reduce infiltration rates. In rare cases where trees are planted in large gardens, they have the potential to benefit from increased infiltration of moisture, nutrients and high oxygen diffusion rates. Elevated planters filled with soil are potential solutions to soil compaction, however, research has established that planters are rarely large enough to support a large rooting system and hence a large crown (Lindsey & Bassuk 1991).

Root growth and density also increase in soil as compared to other surface treatments. The roots of trees planted at the periphery of a paved area grew very densely in the direction of the adjacent gardens, while the portion of the root system growing in the direction of the paved area was sparse (Schwets & Brown 2000). A similar experiment discovered that total root surface area in bare soil exceeded that of trees planted in turf by 113% (Watson 1988). Clearly, the increased levels of available water and nutrients in the bare soil areas provided more hospitable growing conditions for tree roots.

In the absence of protection, bare soil is completely vulnerable to atmospheric conditions and, as such is subject to relatively large temperature fluctuations (Watson & Kupkowski

1991), erosion, and crusting. Temperature fluctuations strongly influence root respiration, which can lead to high CO_2 concentrations in the soil. Erosion, the result of wind and water, can leave roots exposed to mechanical damage while soil crusting seals the soil surface thereby severely decreasing infiltration rates.

Organic Mulch

Mulch is often used in urban plantings for a variety of beneficial purposes. As a surface treatment, mulch limits interspecific competition for water and nutrients from weeds which can not become established in the vicinity covered by the mulch (Haywood 1999). In terms of water relations, mulch also acts as a barrier, which buffers soil moisture from the evaporative effects of the sun (Watson 1988). In addition, soil beneath a mulch layer is protected from compaction, thereby maintaining sufficient porosity and infiltration rates (Lichter & Lindsey 1994). This differs from soils beneath hard surfaces which are highly compacted and turf, which is highly variable. The resulting moisture availability in uncompacted soil beneath the mulch provides conditions in which tree rooting densities increase and total root surface area nearly triples those found in turf-covered soil (Watson 1988).

The application of organic mulch also has implications for temperature relations. Organic mulch is similar to asphalt in that it absorbs radiation energy, and re-radiates it as long-wave thermal energy. As such, it increases leaf temperatures and leaf-to-air vapour pressure deficit (Montague & Kjelgren 2004). It is unclear how these factors will affect stomatal conductance (see above discussion under 'Asphalt'). When whole tree water relations in mulch are considered, the relatively larger root system and increased soil moisture availability may maintain stomatal conductance in response to increased leaf temperatures and leaf-to-air vapour pressure deficit.

Wood chip mulches are also a potential source of nutrients and organic matter, both of which are often deficient in urban soils (Friedrich & Ham 1982). Mulch use has some distinct advantages; nevertheless, there are potential drawbacks that should be noted. Very fine mulch can prevent soil from receiving moisture infiltration as it entirely absorbs precipitation (Watson & Kupkowski 1991). Fine mulch can also cause nitrogen deficiencies due to rapid decomposition (Harris 1983), though this phenomenon is contested (Watson & Kupkowski 1991). Finally, long-term use of mulches can contribute to a reduction in soil pH (Himelick & Watson 1990). Mulch is a costly alternative, so while its benefits are plentiful, the mulching of large numbers of trees could prove to be unfeasible.

Studies to date have shown that soft surfaces, especially non-vegetated ones, are more hospitable for trees than hard surfaces in terms of moisture, nutrient, and temperature stresses. Many of these studies are based strictly in physiological terms and have produced varying results due to differences in study design and climate. In addition, very few of these studies have directly compared more than two surface treatments with regards to tree condition. Thus, in the literature, there exists a lack of a useful and comprehensive comparison of surface treatment.

This study will discern any association between surface treatment and the overall condition of trees planted in them. The goal is to determine whether or not there is interaction between the surface by which a tree is surrounded and its condition, such that visual signs of stress become prevalent. The measure will be species specific in order to determine which species are most suited for planting in specific surface treatments.

Methods

Study Site Description

Data collection was conducted on TDSB properties within the area delimited by Lake Ontario to the South, the Humber Valley to the West, the Don Valley to the East and Eglinton Avenue to the North. This area comprises some of the most heavily developed areas of Toronto. Properties were of variable size and dimension and were surrounded by a variety of land-use types, predominately residential. Data was collected for all trees located on TDSB properties including parking lots, playgrounds, and fields, as well as front, side, and back lawns or gardens at all school sites.

Data Collection and Management

All trees on TDSB properties were inventoried using Neighbour*woods*©, a program designed for the collection of tree attribute data, which collectively define the condition of a tree based on a numerical weighting scheme (Kenney & Puric-Mladenovic 2001). Condition ratings are based on the presence and severity of stressors such as scars, poor branch attachment, defoliation, lean, and rot. Using this system, each tree is assessed demerits, and subsequently classified as *Excellent, Good, Fair, Poor,* or *Very Poor* (see Appendix I for Neighbour*woods*© guide).

In addition to collecting tree condition attributes, size attributes were recorded including crown width, crown height, tree height and stem diameter at breast height (DBH). Finally, the survey included neighbourhood characteristics, such as the location and surface treatment in which trees are planted. Locations were classified as 'High Use' or 'Low Use'. The former location includes areas with play structures, fields or courts, while 'Low Use areas are defined as areas at the front, side, or back of the school which were generally off-limits to students. The surface treatment was determined visually by assessing the surface which occupied the majority of the area under the dripline of each tree's crown. Classifications were generalized as hard or soft, with asphalt and interlocking brick being considered as subclasses of hard surfaces, while turf, mulch and soil were considered as subclasses of soft surfaces.

Data Analysis

The goal of the analysis was to determine if an association exists between surface treatment and condition rating. All statistical tests used a significance level of 0.05. Contingency tables were used to identify associations between several independent variables (surface treatment, location, species, and size) and tree condition rating. Once associations were found between variables, pair-wise comparisons were undertaken to show which categories within a variable were strongly associated with the ratings. Analysis of variance was employed to determine variation amongst size classes, with Tukey post hoc testing to determine differences within classes.

Exploratory analysis revealed insufficient observations to complete Chi-square analysis. Thus concrete, ecostone, flagstone, quads, and turfstone were not included in analysis. A similar rationale requires grouping ‘Very Poor’, ‘Poor’ and ‘Fair’ condition ratings into a single category referred to as ‘Poor’. Grouping was also used to consider trees at the front, back and side of schools as a single category, namely, ‘Low Use’. Trees in parking lots were dismissed as there were too few observations. Thus, only trees in ‘High Use’ and ‘Low Use’ locations were contrasted.

Results

Surface Treatment’s Effect on Condition Rating

It was hypothesized that there would be a significant effect of surface treatment on tree condition rating. However, there was no significant difference in tree condition ratings as a function of surface treatment (χ^2 [DF: 8, N: 2790] = 12.1; p = 0.14). Between 70-85% of all trees were classified as either ‘Good’ or ‘Excellent’ for all surface treatments (Figure 2).

Rated Surface Treatments

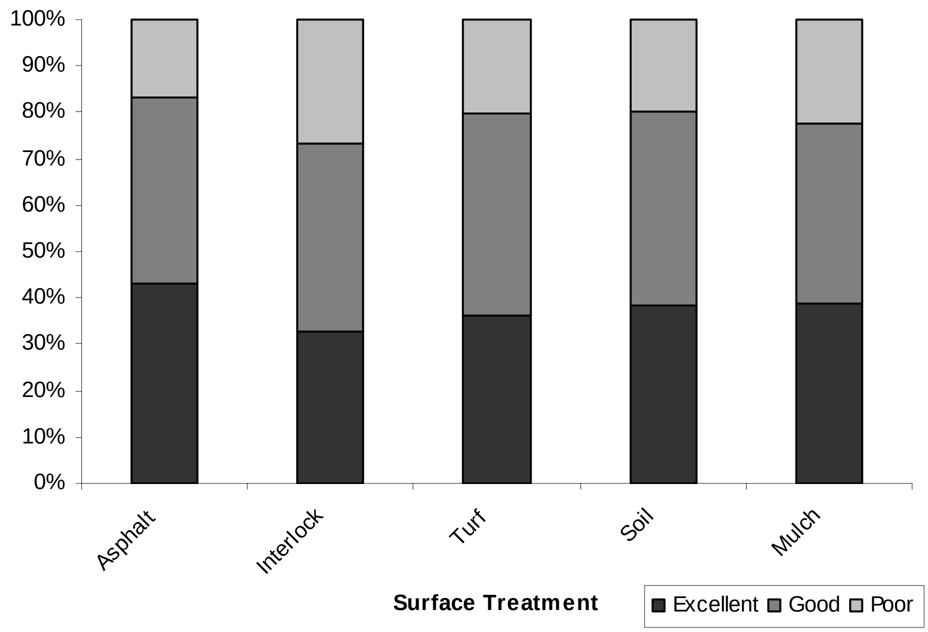


Figure 2. Proportions of 'Excellent', 'Good', or 'Poor' trees within different surface treatments. No significant association between surface treatment and condition rating was found ($\chi 2$ [DF: 8, N: 2790] = 12.1; p = 0.14).

Location's Effect on Condition Rating

Considering the inherent differences between 'Low Use" and 'High Use' locations, there was reason to believe that a relationship between location and condition rating would be present. Yet, the association between location and condition rating was insignificant (χ^2 [DF: 2, N: 2790] = 2.77; p = 0.25), suggesting no appreciable variation in condition rating amongst trees from differing locations. Approximately 40% of trees in both surface treatments were rated as 'Excellent', while roughly 85% were rated as 'Good' or 'Excellent' (Figure 3).

Location's Effect on Condition Rating

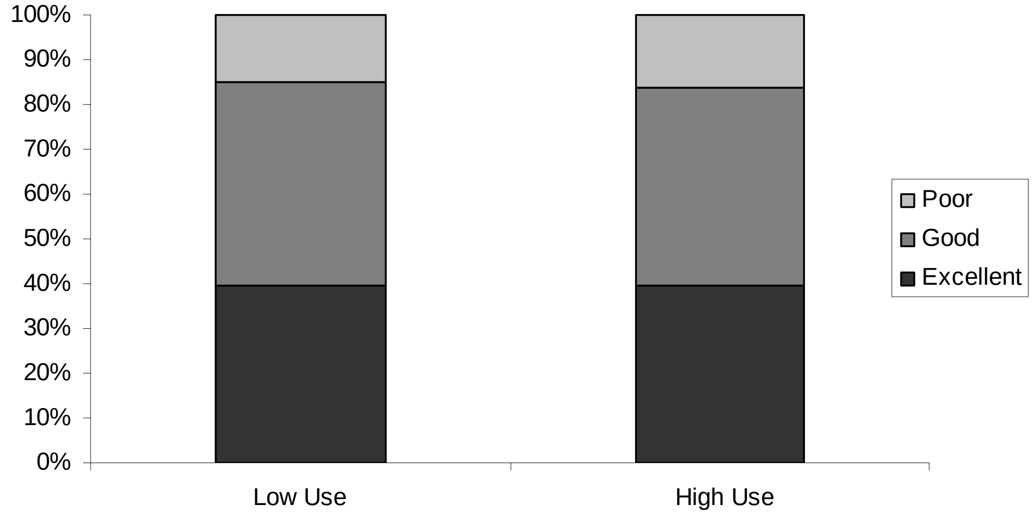


Figure 3. Proportion of 'Excellent', 'Good', and 'Poor' condition ratings with respect to location. There is no significant association between location and condition rating ($\chi 2$ [DF: 2, N: 2790] = 2.77; $p = 0.25$).

Effect of Surface Treatment at Various Locations

A location specific association was expected between surface treatment and condition rating due to the marked differences between high and low use locations. Upon classification of the data into different location types, significant associations were, in fact, present. Surface treatment had a significant effect on tree condition ratings when data was partitioned by location and analyzed separately (Figure 4).

Location-Specific Condition Ratings

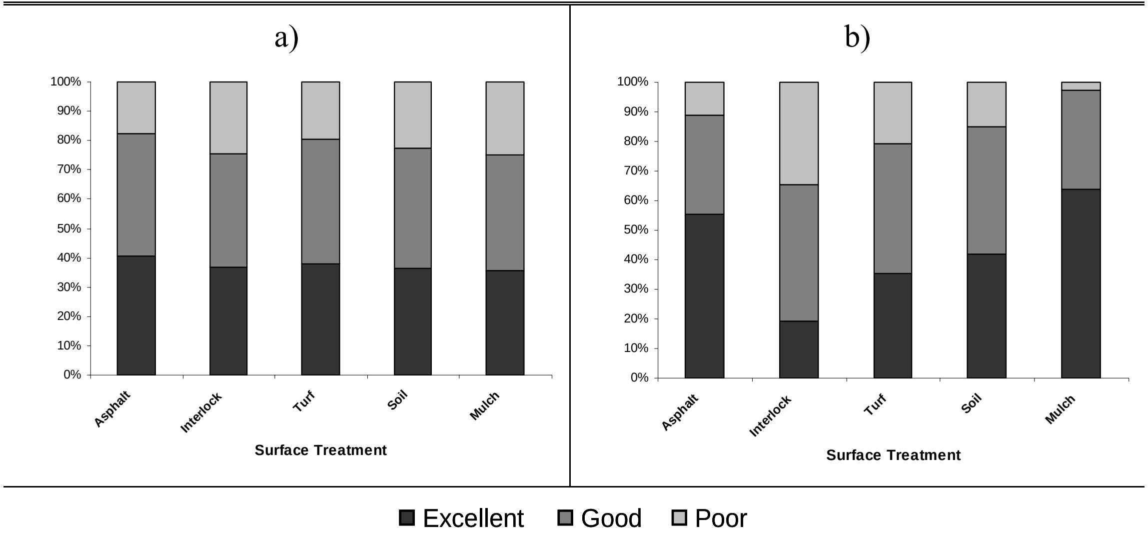


Figure 4. The proportion of 'Excellent', 'Good', and 'Poor' tree condition ratings with respect to location. (a) There is no an association between surface treatment and condition rating in 'High Use' locations ($\chi 2$ [DF: 8, N: 1600] = 7.18; p = 0.52). (b) However, the association becomes evident in 'Low Use' locations ($\chi 2$ [DF: 8, N: 1190] = 32.77; p < 0.0001).

Interestingly, the association is only evident in 'Low-Intensity' areas (χ^2 [DF: 8, N: 1190] = 32.77; p < 0.0001). Mulch was shown to be associated with trees exhibiting the lowest levels of stress, with nearly 100% of trees being classified as either 'Excellent' or 'Good'. Following pair-wise analysis there was found to be no difference between the effect of asphalt and mulch on condition rating (χ^2 [DF: 2, N: 90] = 2.18; p = 0.34). Similarly, no significant effect was found when comparing asphalt and soil (χ^2 [DF: 2, N: 271] = 3.03; p = 0.22). This suggests that between asphalt and mulch surface treatments, there is no significant variation is rating distribution. Conversely, pair-wise comparisons between mulch and the other surface treatments showed significant associations (mulch/interlock: χ^2 [DF: 2, N: 62] = 16.79; p = 0.0002; mulch/turf: χ^2 [DF: 2, N: 893] =14.54; p = 0.0007; mulch/soil: χ^2 [DF: 2, N: 253] = 7.10; p = 0.0286). These results suggest that in 'Low

Use' locations, condition ratings differ significantly between mulch and each of interlock, grass, and soil.

Trees planted in 'High Use' locations were not significantly affected by surface treatment (χ^2 [DF: 8, N: 1600] = 7.18; p = 0.52). Approximately 40% of trees across all surface treatments received 'Excellent' condition ratings, while roughly 80% were considered as 'Good' or 'Excellent'.

Size-Class' Effect on Condition Rating

Assuming that compounding stresses are a function of time since planting, young trees should theoretically be less stressed and thus have higher condition ratings. As tree age was unavailable, this study assumed that trees in the smallest size-class (< 10 cm) were newly planted. A one-way ANOVA identified a significant association between size-class and condition rating ($F(3, 2790)=33.43$, $p < 0.0001$). Post hoc analysis using the Tukey post hock criterion indicated that the mean condition ratings of small (M = 93.86, SE = 0.20) and medium (M = 93.35, SE = 0.13) trees were not significantly different. In addition, the condition ratings of small and medium trees exceeded those of large (M = 92.38, SE = 0.14) and extra large (M = 90.28, SE = 0.46) trees and finally, large trees received higher condition ratings than extra large trees. The lack of association between small (< 10 cm) and medium (10-25 cm) trees suggest that they are similar with respects to their effect on condition rating. There is a steady decline in condition rating with increasing size-class (Figure 5).

Mean Condition Ratings for Differing Size Classes

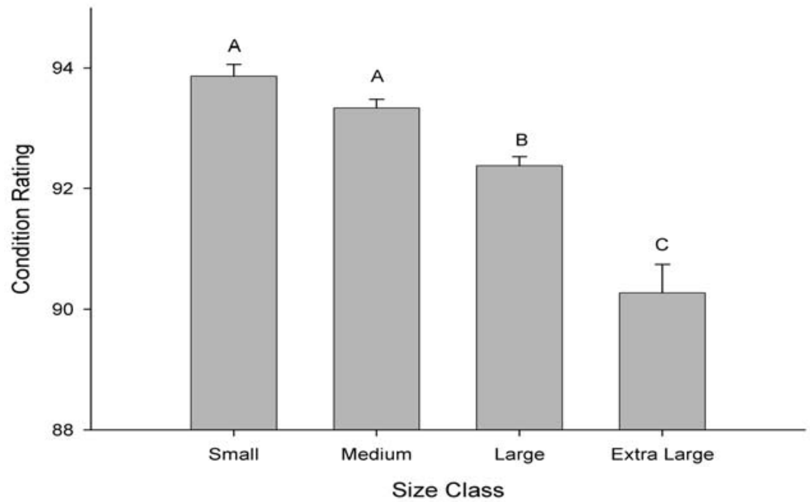


Figure 5. The mean condition ratings for each size class. There exists a significant association between size-class and condition rating ($F(3, 2790)=33.43$, $p < 0.0001$). A decreasing trend is evident as trees grow larger. Size classes with the same letter above the bar are not statistically different at the 0.05 level based on Tukey's post hoc comparison method.

Surface Treatment's Effect on Size-Class

The quality of surface treatments based on tree condition ratings can be over- or understated if size classes are disproportionately represented. Small and medium trees were found to have higher ratings and thus, if their relative abundance is elevated within a particular surface treatment, that surface treatment will emerge superior to others. Conversely, a surface treatment with a skewed size-class distribution favouring large or extra large trees will be represented conservatively by condition ratings. Chi-square analysis supported an association and therefore, size-classes were represented disproportionately amongst surface treatments (Figure 6) (χ^2 [DF: 12, N: 2825] = 107.76; $p < 0.0001$). Pair-wise testing revealed that all surface treatments save for 'Interlock' and

‘Mulch’ had significantly different size-class distributions (Interlock/Mulch χ^2 [DF: 3, N: 432] = 2.74; p = 0.4326). Of note is the large percentage of small trees surrounded by mulch (>30%). Also, the asphalt surface treatment had the lowest number of small trees (<10%). Interestingly, the largest proportion of extra large trees was found in asphalt and turf. Less than 10% of the trees in any of these surfaces are larger than 60cm. The size potential of trees is approximated by reporting the largest trees in each surface treatment.

Size-Class Representation Across Surface Treatments

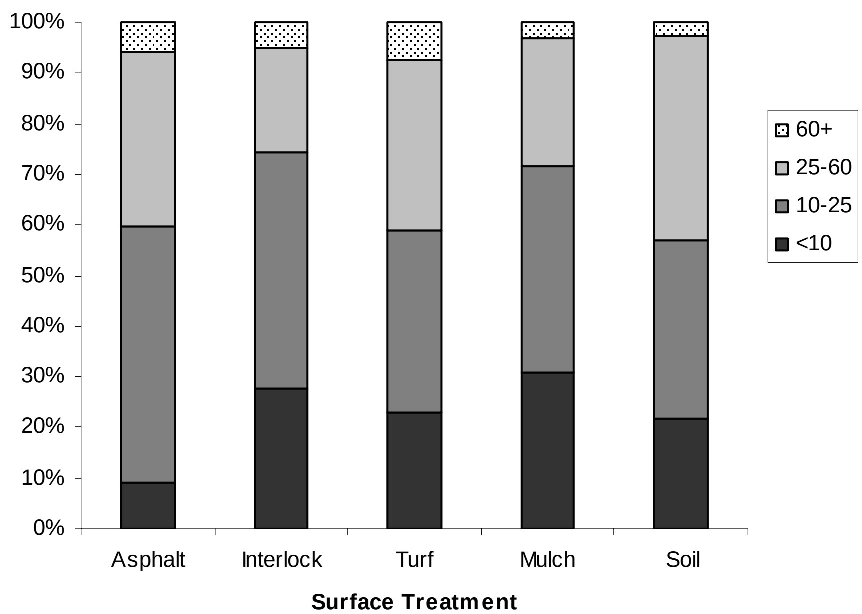


Figure 6. The proportion of each surface treatment occupied by trees of varying size class. There is a significant association between size class distribution and surface treatment (χ2 [DF: 12, N: 2825] = 107.76; p < 0.0001). Only ‘Interlock’ and ‘Mulch’ did not differ significantly with respects to size-class variations (χ2 [DF: 3, N: 432] = 2.74; p = 0.4326).

Location's Effect on Size-Class

A significant association was identified amongst the size class distributions of trees in different locations (χ^2 [DF: 3, N: 2627] = 81.92; $p < 0.0001$) (Figure 7). "High Use" locations were characterized by a high incidence of trees in smaller size classes (< 25 cm). Conversely, the largest size class is represented by a proportionally higher number of trees in 'Low Use' locations.

Size Class Representation in Various Locations

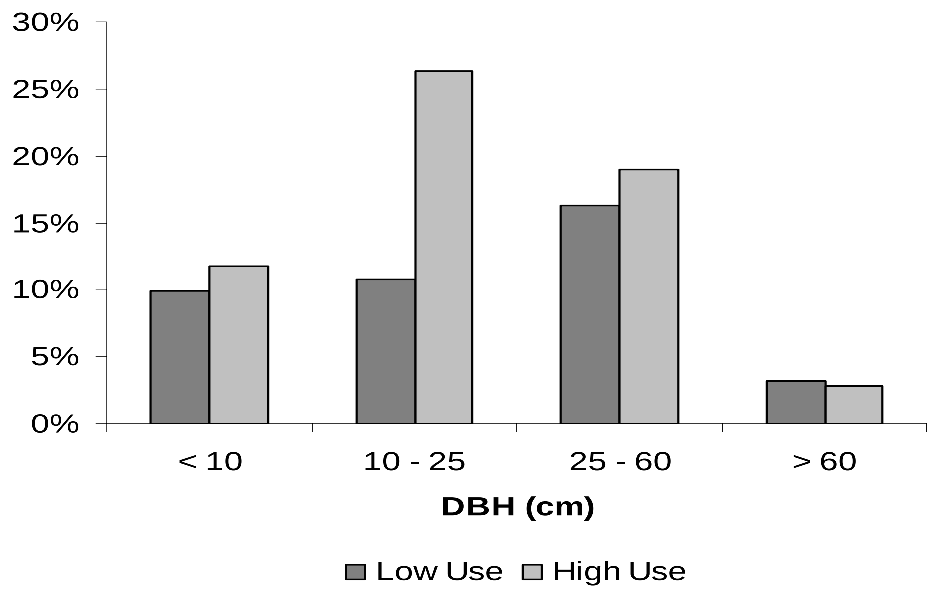


Figure 7. Tree size-class distribution varies with location ($\chi2$ [DF: 3, N: 2627] = 81.92; $p < 0.0001$). While 'High Use' locations have a proportionally higher number trees in smaller size classes, 'Low Use' locations have a larger proportion of trees in the largest size class.

Species Effect on Condition Rating

It is to be expected that based on specific physiological and morphological traits, certain species will be well acclimated to urban conditions. Analysis revealed that an association is present between species and condition rating (χ^2 [DF: 28, N: 2184] = 127.27; p <

0.0001) (Figure 8). Colorado Spruce (*Picea pungens*) was most heavily associated with an 'Excellent' rating (>70%). Other species expressing high proportions of 'Excellent' ratings included: Sugar Maple (*Acer saccharum*), White Ash (*Fraxinus americana*), Red Maple (*Acer rubrum*), Crab Apple (*Malus spp.*), Little-leaf Linden (*Tilia cordata*). These species did not differ significantly from one another with respects to proportion of 'Excellent' ratings. In terms of trees which expressed a significantly higher proportion of 'Excellent' or 'Good' trees, Colorado Spruce and Siberian Elm (*Ulmus pumila*) exceeded all other species. The next group of highly rated trees consisted of Sugar Maple, Red Maple, Honey Locust (*Gleditsia triacanthos*) and White Ash. Conversely, the species which displayed the largest proportion of trees with 'Poor' ratings were Silver Maple (*Acer saccharinum*), Crab Apple, Red Oak (*Quercus rubra*) and Mountain Ash (*Sorbus spp.*).

Condition Rating Distribution Across Abundant Species

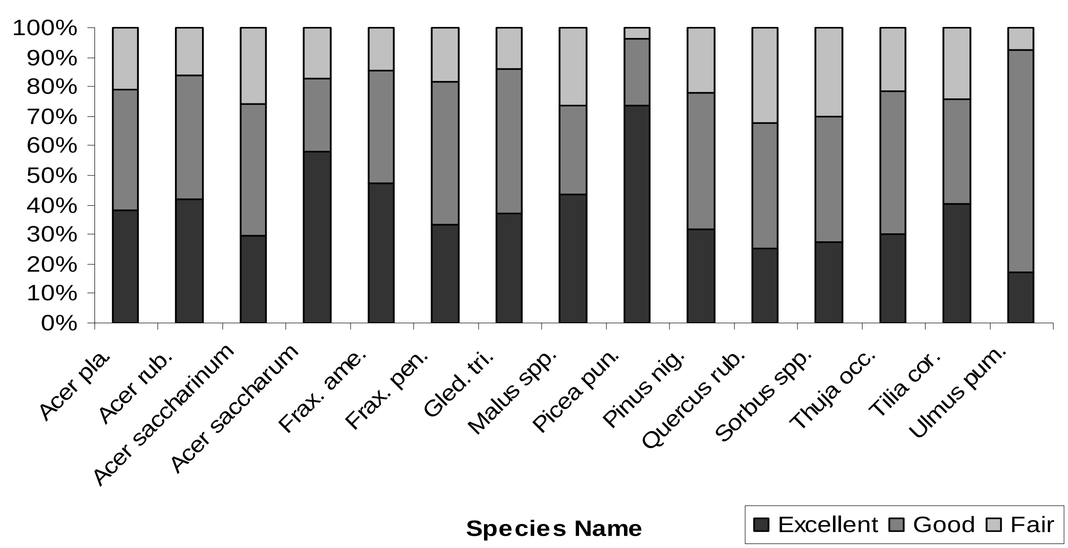


Figure 8. Proportion of each species represented by 'Excellent', 'Good', or 'Poor' trees. There is an association between species and condition rating ($\chi2$ [DF: 28, N: 2184] = 127.27; $p < 0.0001$).

Discussion

Initial results indicate that no association exists between surface treatment and condition rating (Figure 2). Accordingly, it could be concluded that the condition of trees is unaffected by the surfaces that surround them. Considering the large body of research suggesting that hard surfaces have negative impacts on tree physiology, this result seems unusual (see Kjelgren & Montague 1998; Cermak *et al.* 2000).

The initial results, however, were confounded by a location effect. Subsequent classification of trees by location resulted in significant associations, but interestingly, not in all locations. While trees in 'Low Use' locations are influenced by their surface treatments, trees planted in 'High Use' locations are not.

It was expected that the condition ratings of trees in 'Low Use' areas would be well aligned with the literature. While generally true, the results suggest that mulch was associated with the highest condition ratings and was followed by asphalt, soil, turf, and finally interlocking brick. The comparatively high condition rating of trees planted in asphalt surface treatments was unexpected. The condition ratings of trees planted in asphalt surface treatments were not found to differ from those of mulched trees or trees in bare soil. In addition, they significantly exceeded the condition ratings of turf and interlock (Figure 4b). This result is even more interesting considering the relatively small proportion of small trees planted in asphalt, which have the potential to bias ratings in a positive manner (Figure 6). This result contradicts the currently available information regarding asphalt's effect on tree success, the majority of which suggests that asphalt has negative effects on tree roots in terms of water (Celestian & Martin 2004) and nutrient relations (Hodge & Boswell 1993), as well as, gas exchange (Cermak *et al.* 2000). With these detriments inherent to trees surrounded by asphalt, it is difficult to comprehend how their ratings could be significantly superior to those of trees in turf. Clearly, other factors are confounding the condition of trees in 'Low Use' locations.

An inspection of the turf surface treatment revealed significantly fewer 'Excellent' and 'Good' trees than all surfaces except for interlocking brick (Figure 4b). Interestingly, these results suggest that turf is the least hospitable of the three soft surface treatments. This notion is commensurate with many of the results of contemporary research (Watson 1988). Turf is similar to mulch and soil in its ability to allow moisture and nutrient infiltration, as well as gas exchange, however, turf roots are fiercely aggressive for these resources, often out-competing tree roots (Close *et al.* 1996). Another potential cause for the inferior condition ratings of trees in turf is the mechanical damage inflicted upon the stem by grass trimmers.

In order to determine the reasons which account for asphalt's superiority over turf, this report observed the proportion of trees in both surface treatments affected by each stressor. It is evident that when compared to turf, trees in asphalt have a lower proportion of stem cavities, likely an artefact of the lower proportion of stem scars, and cracks (see Appendix II). Interestingly, trees in asphalt exhibit a lower proportion of defoliation and chlorosis, both of which often occur as a result of nutrient deficiencies and poor water status. This suggests that turf roots are outcompeting tree roots for water and nutrients. It should be noted that the TDSB does not fertilize, nor irrigate 'Low Use' locations both of which benefit tree roots (B. Day, personal communication, October 20, 2005). It is highly likely that water and nutrient deficiencies would not be improved in an asphalt surface treatment, however, the stresses resulting from stem abrasion are characteristic of the turf environment.

If the TDSB wishes to improve the condition of trees in 'Low Use' locations, the most effective and efficient method would be to place mulch around those trees planted in turf. Mulch has the potential to improve water and nutrient relations, both of which prevail amongst trees surrounded by turf. In addition to improving water and nutrient relations, mulch provides a buffer between a tree and its surroundings. Thus, the stem is less predisposed to mechanical damage that can result from grass trimmers (see Appendix II). Evidently, mulch provides numerous benefits as observed by the higher condition ratings of trees planted in mulch surface treatments. As such, investment in a mulching program should be considered.

Though an association between surface treatment and condition rating was observed in 'Low Use' locations, trees planted in 'High Use' locations were unaffected. One would expect that trees planted in soft surface treatments (turf, soil, mulch) would exhibit higher condition ratings relative to trees in hard surface treatments (asphalt, interlocking brick). This expectation is reasonable as soft surfaces offer relatively high permeability, which allows infiltration of water and nutrients. These factors have been identified as the greatest influences on urban tree condition (Gilbertson & Bradshaw 1985). In spite of this, trees planted in soft surfaces did not have significantly higher condition ratings than their counterparts in hard surfaces. This suggests that, in ‘High Use’ locations, there are factors other than water and nutrient relations that are influencing condition rating.

One hypothesis is that the intensity of use subjects soft surface treatments to chronic compaction, thus offering little advantage over hard surfaces in terms of water and nutrient infiltration, or gas exchange. The data collected during the course of this research is not sufficient to make assertions regarding this possibility, consequently suggesting the need for further investigation.

Another potential rationalization is that trees in ‘High Use’ locations could be subject to higher degrees of stress than trees in ‘Low Use’ locations. The compounding set of stresses could thus nullify the benefits provided by a soft surface treatment. If this were the case, one would expect higher condition ratings for trees in ‘Low Use’ locations than in ‘High Use’ locations. Though this was not observed (Figure 3), a more in depth inspection revealed that “Low Use’ locations had a proportionally higher number of trees in the largest size class and proportionally lower number of trees in the smaller size classes than trees in ‘High Use’ locations (Figure 7). The significance is that trees in smaller size classes have inherently higher ratings, and thus, location-specific size class distributions have negatively biased the condition ratings of trees in ‘Low Use’ locations and artificially increased the condition ratings of trees in ‘High Use’ locations. Accordingly, trees in ‘High Use’ locations are subject to a larger set of compounding stresses which negate the potentially positive effects of soft surface treatments.

A final explanation is based on a neighbourhood effect. Trees planted in soft surfaces could face negative effects resulting from the large areas of asphalt characteristic of 'High Use' locations. Despite being immediately surrounded by a soft surface (and hence classified as mulch, turf or soil), many trees were planted in an asphalt matrix. Thus, the surrounding asphalt may have contributed to obscuring the benefits provided by the softer surfaces which immediately surround trees. Conversely, asphalt-bound trees could benefit from the proximity of soft surfaces (Schwets & Brown 2000). Thus, a 'High Use' location can provide all trees with comparable access to water and nutrients, depending on its degree of heterogeneity.

Regardless of the rationale, it is clear that due to uncertain circumstances, the condition ratings of trees in 'High Use' locations are not associated with surface treatment. Consequently, there should be no hesitation to plant trees in hard surfaces, when appropriate. This is of prime importance in densely populated, heavily developed urban locales where soft surfaces are rare. Since the availability of soft surfaces should no longer dictate planting location canopy cover can be increased in asphalt and interlocking brick. With improved canopy cover, students will receive benefits such as increased shade-cover, reduced temperatures, shelter from winter winds, improved psychological well-being, and outdoor classrooms.

Though these results suggest that trees planted in 'High Use' locations are unaffected by surface treatment, there is potential to improve overall tree condition across all surface treatments. Planting trees in clusters is a powerful manner by which tree condition can be improved. Clustering provides shade, hence minimizing evapo-transpirational demand and improving water relations (Schwets & Brown 2000). Furthermore, trees in groups are less susceptible to vandalism, thus decreasing stem and branch scars (Gilbertson & Bradshaw 1985). Clearly, proper species selection is also important. The species exhibiting the largest proportion of 'Excellent' trees were: Colorado spruce, sugar maple, white ash, little-leaf linden, crab apple, and red maple.

Conclusion

This report has provided the TDSB with an assessment of the condition of the trees on their properties. To maximize the benefits provided by trees, the TDSB should invest in a mulching program which will improve water and nutrient relations, as well as minimize mechanical damage by providing a buffer. Furthermore, tree planting is encouraged in hard and soft surface treatments alike. Asphalt should no longer be avoided; however, precautions such as planting trees in clusters can improve tree condition and increase survival rates (Schwets & Brown 2000). Finally, species selection with regard for surface treatment can greatly improve the condition of the TDSB's urban forest.

By increasing the potential planting area on TDSB properties, as well as improving the condition of trees in all surface treatments, this report has the potential to influence future planting guidelines at the TDSB. A new, Board-wide tree planting guideline containing specific details regarding tree planting in hard surfaces will result in improved environmental conditions. Students will benefit from increased shade cover, reduced temperatures, shelter from winter winds, and finally, improved psychological well-being.

The results of this study, while commissioned by the TDSB, are applicable at larger scales. In densely populated, heavily developed urban areas, the species-specific planting of trees in hard surfaces has the potential to increase the canopy cover of cities and afford citizens with the ecological services provided by trees.

Literature Cited

1. Akbari, H. 2002. *Shade trees reduce building energy use and CO2 emissions from power plants*. Environmental Pollution 116: S119-S126.
2. Beatty, R. and C.T. Heckman. 1981. *Survey of urban tree programs in the United States*. Urban Ecol. 5: 81-102.
3. Celestian, S. and C. Martin. 2004. *Rhizosphere, surface and air temperature patterns at parking lots in Phoenix, Arizona, U.S.* J. Arboric. 30: 245-252.
4. Cermak, J., J. Hruska, M. Martinkova, and A. Prax. 2000. *Urban tree root systems and their survival near houses analyzed using ground penetrating radar and sap flow techniques*. Plant Soil 219: 103-116.
5. Close, R., P. Nguyen, and J. Kielbaso. 1996. *Urban vs. natural sugar maple growth: stress symptoms and phenology in relation to site characteristics*. J. Arboric. 22: 144-150.
6. Crane, L.A., A.C. Marcus, and D.K. Pike. 1993. *Skin cancer prevention in preschools and daycare centers*. J. Sch. Health 63: 232-234.
7. Cregg, B. 1995. *Plant moisture stress of green ash trees in contrasting urban sites*. J. Arboric. 21: 271-276.
8. Davies, R.J. 1985. *The importance of weed control and the use of tree shelters for establishing broad-leaved trees on grass-dominated sites in England*. Forestry 58: 167-180.
9. Dunster, J.A. 1998. *The role of arborists in providing wildlife habitat and landscape linkages throughout the urban forest*. J. Arboric. 24: 160-167.

10. Fraedrich, S.W. and D.L. Ham. 1982. *Wood chip mulching around maples: effect on tree growth and soil characteristics*. J. Arboric. 8: 85-89.

11. Geller, A.C., L. Rutsch, K. Kenausis, P. Selzer, and Z. Zhang. 2003. *Can an hour or two of sun protection education keep the sunburn away? Evaluation of the Environmental Protection Agency's SunWise School Program.* Environ. Health. 2: 1-9.

12. Gilbertson, P. and A. Bradshaw. 1985. *Tree survival in cities: the extent and nature of the problem*. Arboric. J. 9: 131-142.

13. Harris, R.W. 1983. Arboriculture: care of trees, shrubs, and vines in the landscape. Prentice-Hall, Englewood Cliffs, NJ.

14. Haywood, J.D. 1999. *Durability of selected mulches, their ability to control weeds, and influence growth of loblolly pine seedlings*. New Forest 18: 263-276.

15. Heckel, P.F. 2004. *Using trees to mitigate pollution*. Proceedings of the Air and Waste Management Association's Annual Meeting and Exhibition. pp 4019-4031.

16. Hernandez, B. and M.C. Hidalgo. 2005. *Effects of urban vegetation on psychological restorativeness*. Psychol. Rep. 96: 1025-1028.

17. Himelick, E.B. and G.W. Watson. 1990. *Reduction of oak chlorosis with wood chip mulch treatments*. J. Arboric. 16: 275-278.

18. Hodge, S. 1991. *Urban trees – a survey of street trees in England*. Forestry Commission Bulletin 99.

19. Hodge, S. and R. Boswell. 1993. *A study of the relationship between site conditions and urban tree growth*. J. Arboric. 19: 358-367.

20. Horsley, L., A. Charlton, and C. Waterman. 2002. *Current action for skin cancer risk reduction in English schools: Pupils' behaviour in relation to sunburn.* Health Educ. Res. 17: 715-731.

21. Kenney, A. and D. Puric-Mladenovic. 2001. Neighbourwoods© Tree Inventory Manual. Toronto, ON: Faculty of Forestry, University of Toronto.

22. Kjelgren, R. and J. Cleveland. 1994.

23. Kjelgren, R. and T. Montague. 1998. *Urban tree transpiration over turf and asphalt surfaces*. Atmos. Environ. 32: 35-41.

24. Kozlowski, T. 1999. *Soil compaction and growth of woody plants*. Scandinavian Journal of forest Research 14: 596-619.

25. Lichter, J.M. and P.A. Lindsey. 1994. *The use of surface treatments for the prevention of soil compaction during site construction*. J. Arboric. 20: 205-209.

26. Lindsey, P. and N. Bassuk. 1991. *Specifying Soil Volumes to Meet the Water Needs of Mature Urban Street Trees and Trees in Containers.* J. Arboric. 17: 141-149.

27. Livingston, P.M, V.M. White, A.M. Ugoni, and R. Borland. 2001. *Knowledge, attitudes and self-care practices related to sun protection among secondary students in Australia*. Health Educ. Res. 16: 269-278.

28. Long-Sheng Mao, Yong Gao, and Wen-Quan Sun. 1993. *Influences of street tree systems on summer micro-climate and noise attenuation in Nanjing City, China.* Arboricultural Journal 17: 239-251.

29. McPherson, E.G. 1994. *Using urban forests for energy efficiency and carbon storage*. Journal of Forestry 92: 36-41.

30. Montague, T. and R. Kjelgren. 2004. *Energy balance of six common landscape surfaces and the influence of surface properties on gas exchange of four containerized tree species.* Sci. Hortic. 100:229-249.

31. Nowak, D., J. McBride and R. Beatty. 1990. *Newly planted street tree growth and mortality*. J. Arboric. 16:124-129.

32. Proseus, T.E., G.-L. Zhu, and J.S. Boyer. 2000. *Turgor, temperature, and the growth of plant cells: using Chara corallina as a model system*. J. Exp. Bot. 51: 1481-1494.

33. Schwets, T. & R. Brown. 2000. *Form and Structure of maple trees in urban environments.* Landscape Urban Plan. 46: 191-201.

34. Wagar, J. and A. Franklin. 1994. *Sidewalk effects on soil moisture and temperature*. J. Arboric. 20: 237-238.

35. Watson, G. 1988. *Organic mulch and grass competition influence tree root development*. J. Arboric. 14: 200-203.

36. Watson, G. and G. Kupkowski. 1991. *Effects of a deep layer of mulch on the soil environment and tree root growth*. J. Arboric. 17: 242-245.

37. Wen, D., Y. Kuang, and G. Zhou. 2004. *Sensitivity analyses of woody species exposed to air pollution based on ecophysiological measurements.* Environ. Sci. Pollut. R. 11: 165-170.

38. Whitlow, T.H., N. Bassuk, D. Reichert. 1992. *A 3-year Study of Water Relations of Urban Street Trees.* J. Appl. Ecol. 29: 436:450.

39. Xiao, Q., E.G. McPherson, J.R. Simpson, S.L. Ustin. 1998. *Rainfall interception by Sacramento's urban forest*. J. Arboric. 24: 235-243.

40. Zajicek, J., and J. Heilman, 1991. *Transpiration by crape myrtle cultivars surrounded by mulch, soil, and turfgrass surfaces*. HortSci. 26: 1207–1210.

APPENDIX I

The following is a description of each symptom of stress and its associated demerit value.

Percent Hard Surface

0	The tree is growing in an area with no hard surface.
1	Between 0-25% of the area under the dripline of the tree is hard surface (concrete, asphalt, bricks etc.) or 25-50% of the area is compacted soil.
2	Between 25-50% of the area under the dripline of the tree is hard surface (concrete, asphalt, bricks etc.) or 50-75% of the area is compacted soil.
3	Between 50-75% of the area under the tree is hard surface (concrete, asphalt, bricks etc.) or 75-100% of the area is compacted soil.
4	Between 75-100% of the area under the dripline of the tree is hard surface (concrete, asphalt, bricks etc.).

Unbalanced Crown

0	There are no signs that the crown is unbalanced or lopsided; crown normally developed.
1	Crown slightly asymmetrical due to restricted growing space or lack of light.
2	Crown is asymmetrical, unbalanced or lopsided.
3	Crown is severely asymmetrical to the point where it clearly places damaging stress on the main stem or root system.

Reduced Height

0	There are no signs that tree height has been reduced. Crown has not been topped or pollarded.
1	Less than ¼ of the crown volume has been removed.
2	¼ to ½ of the crown volume has been removed.
3	More than ½ of the crown volume has been removed leaving behind only a few stubs.

APPENDIX I (cont'd)

Weak or Yellowing Foliage

0	Leaves are normal size, color, and texture.
1	Leaves appear to be somewhat smaller than normal; pale in colour.
2	Leaves are significantly smaller than what is normal; pale foliage; thinning of foliage; the crown is significantly more transparent than typical for the species.
3	Leaves are dramatically smaller than normal and/or leaf colour is dramatically different; the crown is very transparent; the tree appears to be in a serious state of decline.

Crown Defoliation

0	The tree crown is not defoliated (healthy). Allow for minor twig defoliation, which is normal in a healthy tree.
1	There are trace amounts of defoliation and less than ¼ of the crown has lost its leaves; crown slightly defoliated.
2	¼ to ½ of the crown has lost its leaves; crown moderately defoliated.
3	More than ½ of the crown has lost its leaves; crown severely defoliated.

Dead or Broken Branches

0	Tree does not have major dead branches; small branches within the inner crown should not be considered. The tree may have one or more minor dead or broken branches or stubs.
1	At least one dead or broken branch, or stub greater than 7cm in diameter is present. Its diameter is less than ¼ the diameter of the next order branch or main stem at the point of attachment.
2	The tree has one or more dead or broken branches or stubs but its diameter is ¼ to ½ of the diameter of the next order branch or main stem at the point of attachment.
3	The tree has one or more dead or broken branches or stubs but its diameter is greater than ½ of the diameter of the next order branch or main stem at the point of attachment.

APPENDIX I (cont'd)

Poor Branch Attachment

0	Branches are properly attached; there are no signs of poor attachment.
1	A V-shaped union between a minor branch and the main stem (the diameter of the branch is ½ or less than the diameter of the main stem at point of attachment). There is no evidence of included bark, but the angle of the fork is such that there is a potential for this to appear as the tree grows. This includes epicormic shoots following topping, pruning or storm damage, etc.
2	As in 1, but the branch is more than ½ of the diameter of the branch or main stem where it is attached; there is evidence of included bark but no breakage. This includes epicormic shoots resulting from poor pruning or breakage, and multiple trunks or codominant stems.
3	As in type 2, but with evidence of a crack between the stems.

Lean

0	The tree is virtually vertically positioned over the base of the stem.
1	Slight or minor lean (<15º from vertical) but no apparent danger.
2	Slight or minor lean (<15º from vertical) with some evidence of root mounding or soil cracking on the side of the tree away from the lean.
3	Serious lean (>15º from vertical) with some evidence of root mounding or soil cracking on the side of the tree away from the lean.

Stem Scars

0	The tree does not have any scars, or scars have healed over.
1	One or more scars with a width totaling 1/8 to ¼ of the circumference, OR a scar less than 1/8 but more than 50cm in length.
2	One or more scars with a width totaling ¼ to ½ of circumference, or 1/8 to ¼ the circumference but more than 50cm in length, or as type 1 but occurring more than once.
3	One or more scars with a width totaling more than ½ the circumference of the stem, or it is between ¼ and ½ of the circumference but more than 50cm in length, or as in type 2 but occurring more than once.

APPENDIX I (cont'd)

Branch Scars

0	The tree does not have any scars, or scars have healed over.
1	One or more minor branch scars or stubs. Diameter of the scar is less than ¼ of the diameter of the next order branch or main stem at point of attachment.
2	Diameter of the scar is between ¼ and ½ the diameter of the next order branch or main stem at point of attachment, or as in type 1 occurring more than once.
3	One or more main (scaffold) branch scars. Diameter is more than ½ the diameter of the main stem at point of attachment, or as in type 2 occurring more than once.

Conks

0	The absence of conks.
1	The presence of conks.

Rot or Cavity (stem and branch separately)

0	Tree does not have any sign of rot or cavity.
1	Rot or cavity is 1/8 to ¼ of the diameter of a major branch or main stem.
2	Rot or cavity is ¼ to ½ of the diameter of a major branch or main stem.
3	Rot or cavity is more than ½ of the diameter of a major branch or main stem.

Cracks

0	Tree does not have major cracks in trunk or main branches.
1	One minor crack extends into the stem, major stubs or branches of significant size. A minor crack is one that enters the wood (not just the bark) but does not extend more than ½ the distance to the centre of the stem.
2	Two or more minor cracks occur in the same general area of the stem, but there are no other defects in contact with the cracks; the crack condition is more serious than type 1, but less serious than type 3.
3	A crack(s) is in contact with another defect (e.g. rot, poor branch attachment, lean); tree has one deep crack where ½ of the tree diameter or more is structurally compromised; cracks in the tangential (horizontal) plane.

APPENDIX I (cont'd)

Confined Space

0	No obstruction or conflicts are apparent in the area within the dripline of the tree.
1	An obstruction exists which would eliminate root development in an area less than ¼ of the area within the dripline of the tree.
2	An obstruction exists which would eliminate root development in an area between ¼ and ½ of the area within the dripline of the tree.
3	An obstruction exists which would eliminate root development in an area more than ½ of the area within the dripline of the tree.

Surface Roots

0	There are no exposed surface roots.
1	¼ of the roots are close to surface or exposed.
2	¼ to ½ of the roots are close to the surface or exposed.
3	More than ½ of the roots are close to the surface or exposed.

Girdling Roots

0	There are no signs of girdling roots on the surface or on the trunk.
1	Girdling roots on the surface but there is not trunk swelling yet.
2	Between type 1 and type 3.
3	A typical butt swelling either with girdling roots seen at the soil surface or exposed.

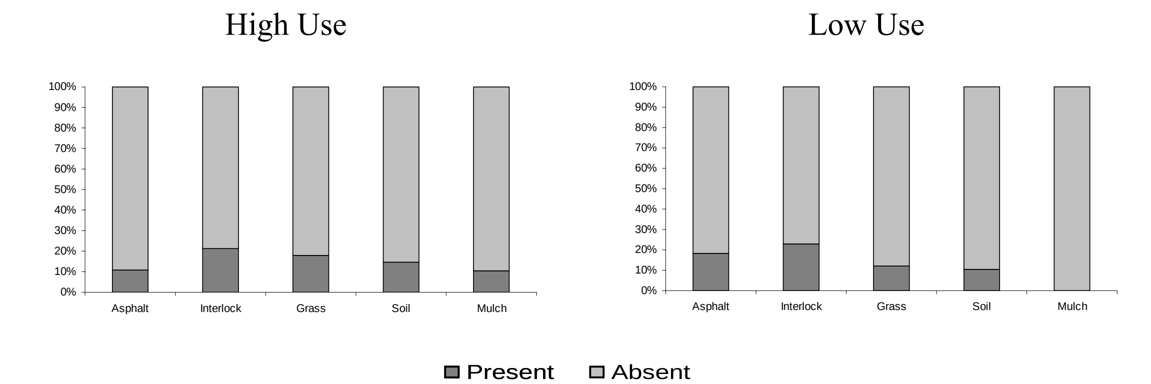
Root Trenching

0	There are no signs of root trenching or cutting within the rooting area.
1	Up to ¼ of the root system has been cut during excavation or trenching.
2	Between ¼ and ½ of the root system has been cut during excavation or trenching.
3	More than ½ of the root system has been cut during excavation or trenching.

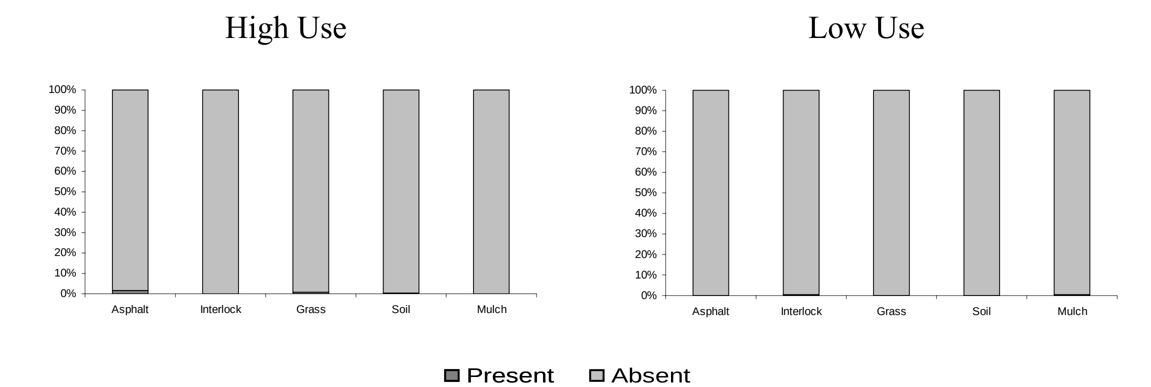
APPENDIX II

The following is a graphically describes how each symptom of stress was represented in both High- and Low-Use Locations.

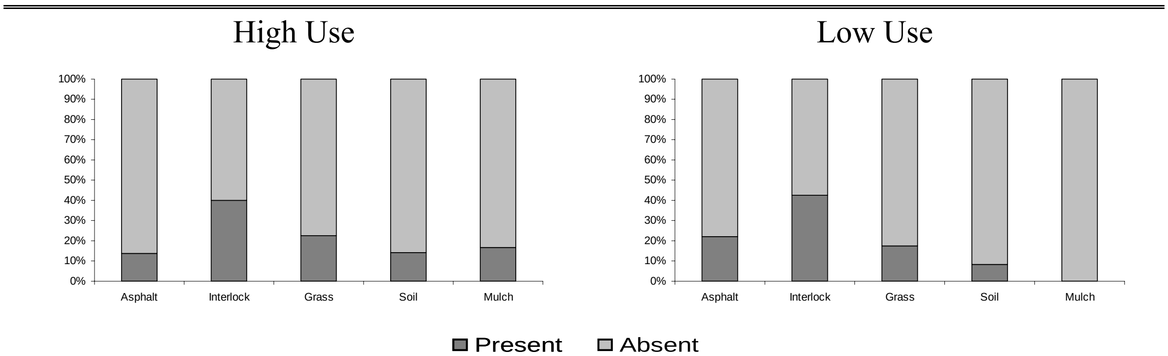
Poor Branch Attachment



Branch cavity or rot

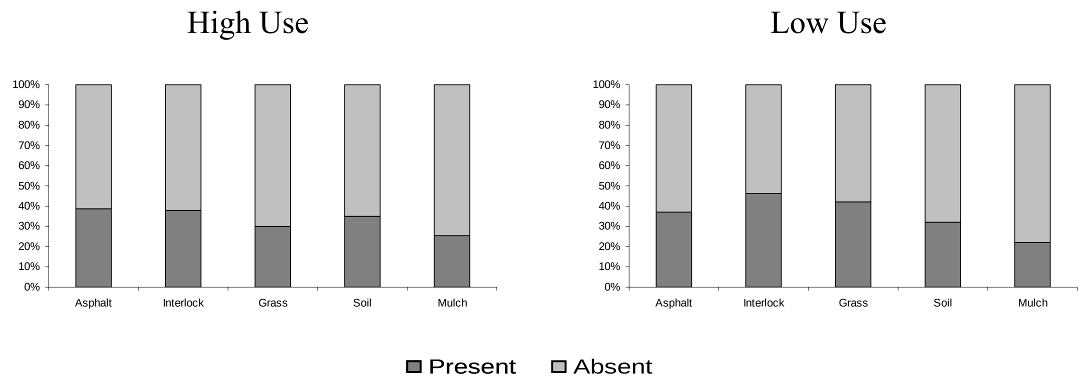


Branch scar

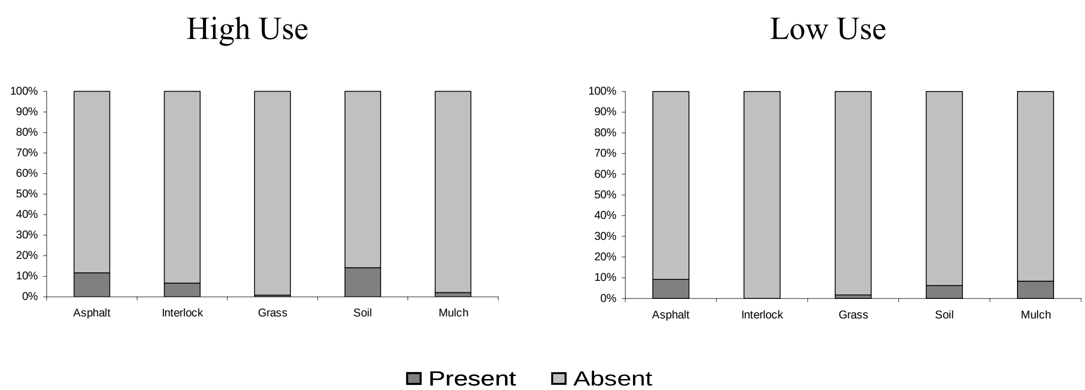


APPENDIX II (cont'd)

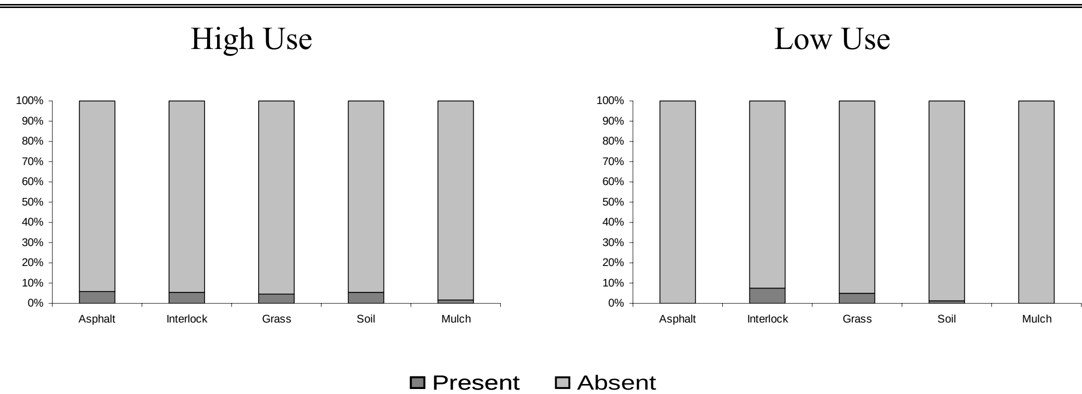
Weak or yellow foliage



Confined space

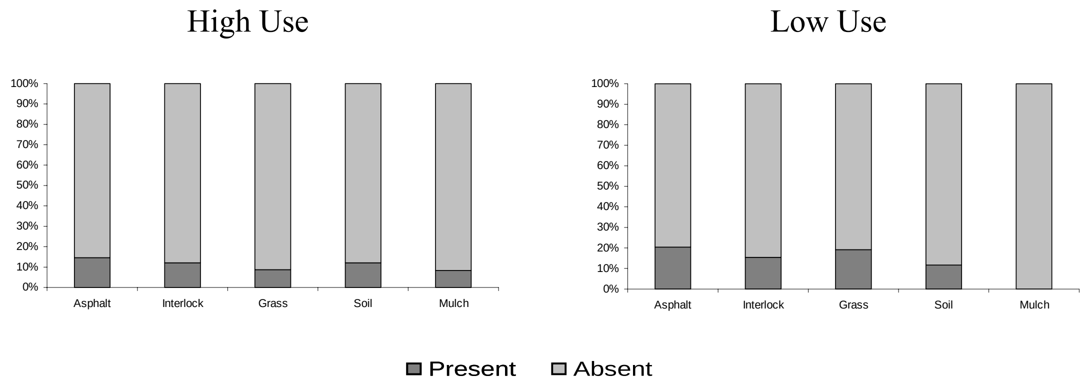


Crack

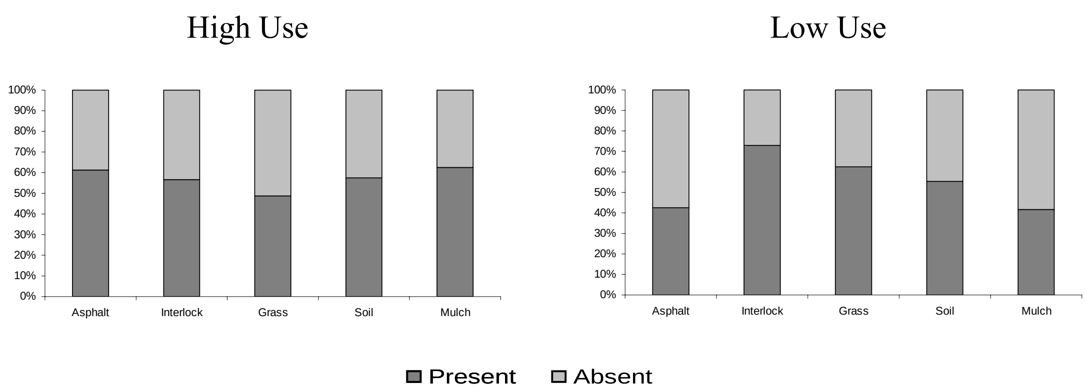


APPENDIX II (cont'd)

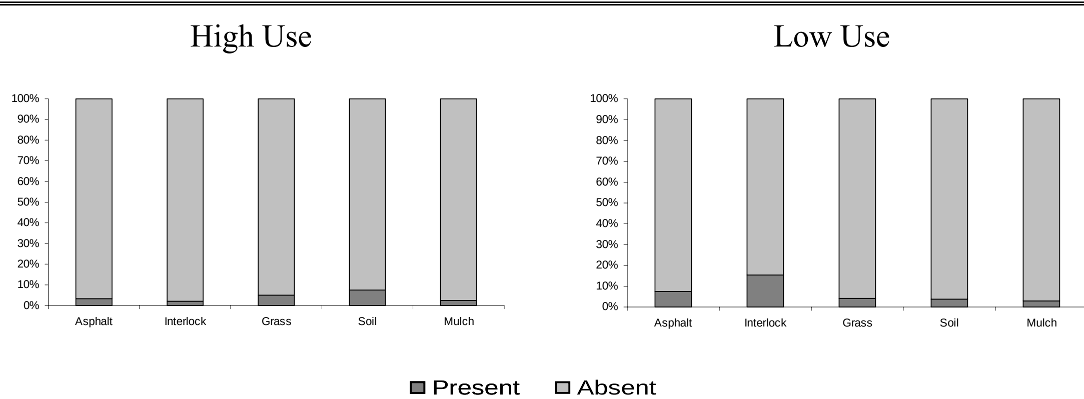
Dead or broken branch



Defoliation

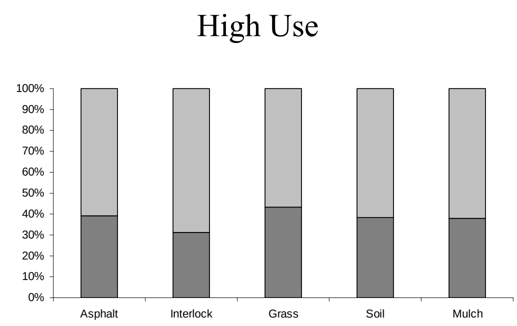


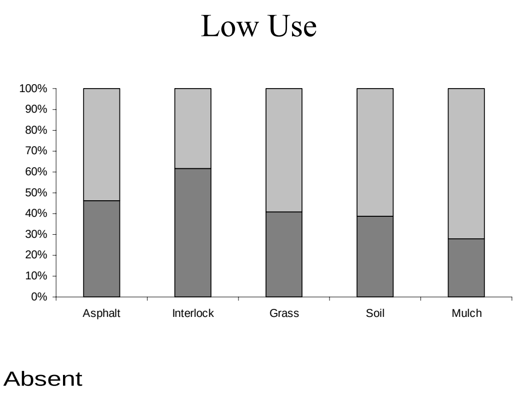
Girdling roots



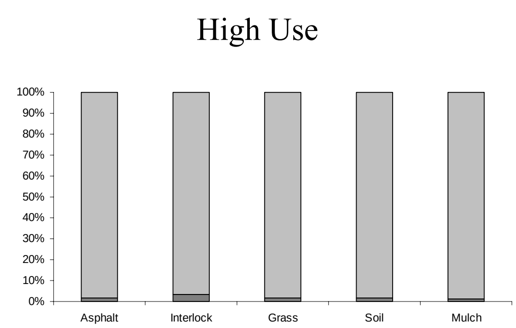
APPENDIX II (cont'd)

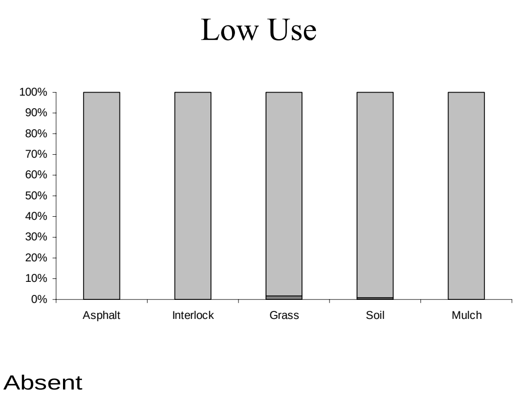
Lean



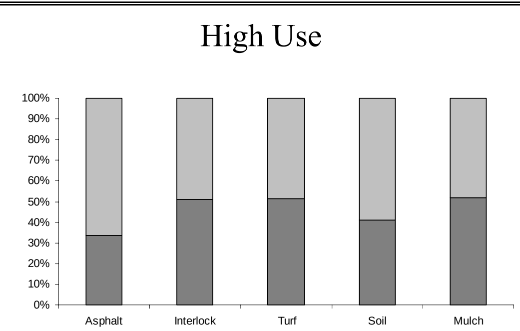


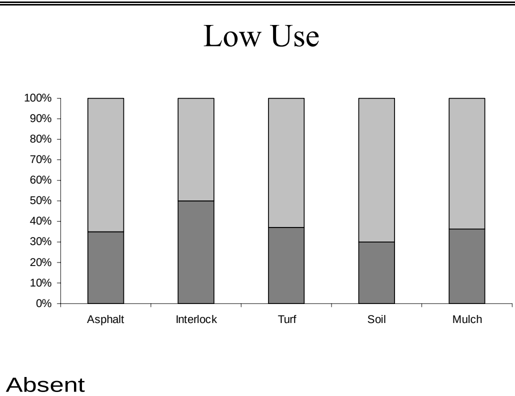
Stem cavity or rot





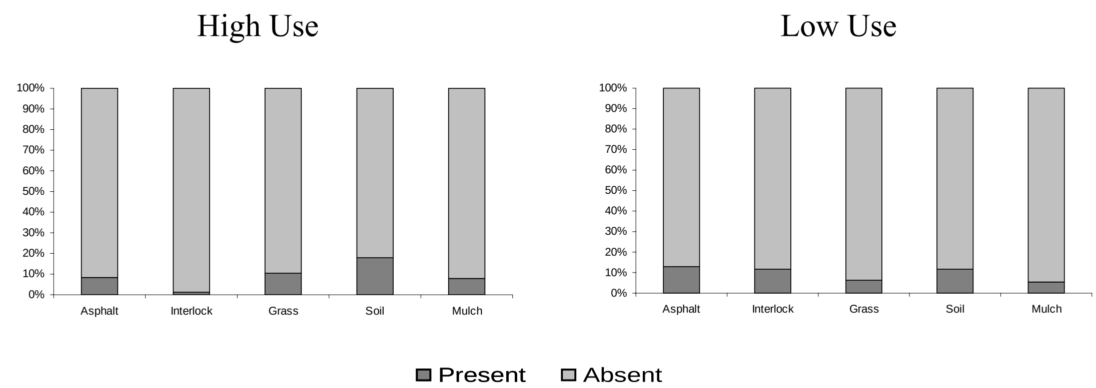
Stem scar





APPENDIX II (cont'd)

Surface roots



Unbalanced crown